1992-09

Multispectral Imagery: an essential tool for today's Naval operations

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http://hdl.handle.net/10945/23976

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

3. DISTRIBUTION/ AVAILABILITY OF REPORT
Approved for public release; distribution is unlimited.

2b. DCLASSIFICATION/DOWNGRADING SCHEDULE

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Naval Postgraduate School

6b. OFFICE SYMBOL *(If Applicable)*
38

7a. NAME OF MONITORING ORGANIZATION
Naval Postgraduate School

6c. ADDRESS *(city, state, and ZIP code)*
Monterey, CA 93943-5000

7b. ADDRESS *(city, state, and ZIP code)*
Monterey, CA 93943-5000

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

6b. OFFICE SYMBOL *(If Applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(city, state, and ZIP code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
MULTISPECTRAL IMAGERY: AN ESSENTIAL TOOL FOR TODAY'S NAVAL OPERATIONS

12. PERSONAL AUTHOR(S)
Burgess, Diane E.

13a. TYPE OF REPORT
Master's Thesis

13b. TIME COVERED
FROM TO

14. DATE OF REPORT *(year, month,day)*
September 1992

15. Page Count
106

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES

FIELD	GROUP	SUBGROUP

18. SUBJECT TERMS *(continue on reverse if necessary and identify by block number)*
Multispectral imagery; LANDSAT; SPOT; satellites; reconnaissance; remote sensing

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This thesis examines the essential use of Multispectral Imagery (MSI) land remote sensing data in support of future military operations, specifically naval operations. The importance of proper management of the Landsat program and funding are discussed in depth. Results of surveys from intelligence specialists and operators express the interest of the Fleet in the need for MSI for future military operations. To continue its lead in remote sensing systems the U. S. must consider foreign competition, such as that from the French Spot system. Examination of this competition, how the U. S.will cope with it, and planning implications from the spread of MSI, are discussed.

Recommendations for the future of the Landsat program and MSI are listed.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
[X] UNCLASSIFIED/UNLIMITED [ ] SAME AS RPT. [ ] DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
CDR R. Mitchell Brown III

22b. TELEPHONE (Include Area Code)
(408) 646-2286

22c. OFFICE SYMBOL
Code NS Br

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Approved for public release; distribution is unlimited.

MULTISPECTRAL IMAGERY: AN ESSENTIAL TOOL FOR TODAY'S NAVAL OPERATIONS

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Submitted in partial fulfillment of the requirements for
the degree of

MASTER OF ARTS IN NATIONAL SECURITY AFFAIRS

from the

NAVAL POSTGRADUATE SCHOOL
September 1992

Thomas C. Bruneau, Chairman
Department of National Security Affairs

ABSTRACT

This thesis examines the essential use of Multispectral Imagery (MSI) land remote sensing data in support of future military operations, specifically naval operations. The importance of proper management of the Landsat program and funding are discussed in depth. Results of surveys from naval intelligence specialists and operators express the interest of the Fleet in the need for MSI for future military operations. To continue its lead in remote sensing systems, the U. S. must consider foreign competition, such as that from the French Spot system. Examination of this competition, how the U. S. will cope with it, and planning implications from the spread of MSI capabilities are discussed.

Recommendations for the future of the Landsat program and MSI are listed.

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EXECUTIVE SUMMARY

MULTISPECTRAL IMAGERY:

AN ESSENTIAL TOOL FOR TODAY'S NAVAL OPERATIONS

The use of Multispectral Imagery (MSI) from land remote sensors, such as Landsat and Spot, is invaluable to support planning for military and particularly, naval operations. The advantages of MSI were effectively demonstrated to the operations and intelligence communities when MSI products were used in support of U. S. and allied forces deployed during Operations Desert Shield/Storm.

This thesis examines MSI requirements for the future and for management of the U. S. Landsat program. Also discussed is the effect that foreign competition and their growing MSI capabilities could signify for U. S. national security.

Thesis research survey responses from naval intelligence specialists and operators stress the increasing requirements MSI information and suggest future uses. The most frequently cited required use of MSI from these respondents was for near-shore bathymetry and beach analysis. Interest was also apparent in receipt of timely data. For MSI to be incorporated into operational planning, the imagery data needs to be received in near-real time. Concern also was expressed that data dissemination be received at the lowest possible level (ship of squadron). Additionally, operational security (OPSEC) was of some concern, but the respondents offered no

feasible suggestions on what could be done to improve OPSEC.

MSI-capable systems and information already are available commercially worldwide, and the proliferation of foreign MSI capable systems challenges the U. S.'s current advantage as the leader in MSI capabilities. Countering this competition through restrictions on proliferation is not a realistic option. Instead, the U. S. must increase its commanders' knowledge on available MSI data to deployed forces. In other words, we must be wiser in our use of MSI data and capabilities than any of our potential adversaries.

While Landsat capabilities have been available for 20 years, the program is still not on a steady course. Having been bounced from one agency to another, including its current management by the private sector, Landsat requires a permanent home. This thesis explores agency options to manage the Landsat program. The most recent plan, with NASA and DOD as joint managers, is probably the most logical. Within DOD, management of Landsat data through the Central Imagery Office would be the most practical.

As Chapter VII on foreign competition points out, the playing field for our military forces is no longer a one-sided advantage to the U. S. To ensure national security objectives, the U. S. must continue as the world leader in MSI capabilities and applications, and we must realize the capabilities of our potential adversaries and counter them with our preparedness.

I. INTRODUCTION

> A remote sensing capability such as is currently being provided by Landsat satellites 4 and 5 benefits the civil and national security interests of the United States and makes contributions to the private sector which are in the public interest. For these reasons, the United States government will seek to maintain continuity of Landsat-type data. (President Bush, 1992)

Remote sensing is essential to the support of national security. It has supported military operations in ways that other information has not, such as broad area coverage of the Iraqi desert. While land remote sensing will be referred to throughout this thesis, the term Multi-Spectral Imagery (MSI) will be used more frequently. Land remote sensing refers to satellite-based sensing of the earth, whether it be through infra-red, thermal, or visual sensors. MSI refers to the imagery data that is recovered from the land remote sensing system. While it is recognized that MSI capabilities can be placed aboard airborne platforms, such as aircraft, MSI, in the context of this paper will refer to satellite-borne land remote sensing data.

MSI, from the U. S.'s Landsat and France's SPOT systems, was used extensively by the U. S. during the Gulf War in 1991. The author understands the importance of MSI to support the range of military operations, from non-combat evacuation (NEO) and humanitarian assistance missions through combat missions, and feels that the importance of this information needs to be

disseminated to operators who would benefit from its use. During research and interviews for this thesis, it became apparent that efforts concerning the use and future of MSI have been put forth at all levels in Washington D. C., at Naval Space Command (NAVSPACECOM) Dahlgren, VA, at Naval Space Command Detachment (NAVSPACECOM DET) Colorado Springs, CO, and at the Marine Corps Intelligence Center (MCIC) Quantico, VA. However, it was also quite apparent during research that operators and intelligence officers who would actually use this information for planning, still knew very little about MSI capabilities. These respondents had outstanding suggestions on future requirements, dissemination, and timeliness of MSI data. Although this paper just scratches the surface of MSI, it is aimed at educating the Fleet about its use and therefore should receive the widest possible dissemination.

Chapter II presents a brief overview on the development of the Landsat program and a description of how land remote sensing systems work. Chapter III is a summary of previous studies on requirements for MSI for the Department of Defense (DOD), particularly for the Department of the Navy. Chapters IV and V are studies of requirements for MSI from intelligence officers and specialists, and operators, respectively. The surveys[1] used for these chapters go beyond requirements and

[1] See Appendix A for survey sample questions.

include topics such as timeliness of dissemination, level of distribution of MSI information and operational security concerns. The same survey technique was used for both groups to determine if responses would be similar or different. Chapter VI is a discussion of the future of MSI capabilities, particularly the U. S.'s remote sensing program and Landsats -6 and -7. The Brown[2] and Pressler[3] Bills and their influence on the Landsat program are discussed. The role of the new Central Imagery Office (CIO)[4] and how it can meet DOD MSI requirements and distribution needs is presented, as is how various DOD agencies are using MSI. Interviews with personnel working with MSI within DOD are included in this chapter. Chapter VII discusses foreign remote sensing systems and the seriousness of their likely impact on U. S. national security.

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[2]The National Landsat Policy Act of 1992, also known as the Brown Bill, shifted oversight of the Landsat program from the National Oceanic and Atmospheric Administration (NOAA) to the Department of Defense (DOD) and National Aeronautics and Space Administration (NASA). The Bill also offered a two-tier pricing system for the purchase of MSI data. This Bill is discussed in more detail in Chapter VI.

[3]The Land Remote Sensing Policy Act of 1992, also known as the Pressler Bill, is similar to the Brown Bill. The major difference being that Pressler proposed that all Landsat data be sold to everyone at the same price. This Bill will be discussed further in Chapter VI.

[4]The CIO was established within the DOD to ensure that U. S. Government "...intelligence, mapping, charting and geodesy and other needs for imagery are met effectively and efficiently in a manner conducive to national security..." (Cheney, 1992) See Chapter VI for further discussion on the CIO.

Chapter VIII provides conclusions pertaining to the future of MSI.

II. LANDSAT - THE FORMATIVE YEARS

In August 1959, the first space photograph of the earth was transmitted by the Explorer 6 satellite (Geodynamics, 1990). Since then civil remote sensing has been relied upon heavily to support science and industry (Geodynamics, 1990). The U. S. military is also coming to rely more on MSI remotely sensed data for its operations.

In the early 1960's, NASA and the Department of the Interior (DOI)[5] began a cooperative program to study the feasibility of launching a series of Earth Resources Technology Satellites (ERTS). On 23 July 1972, ERTS-1 was launched as the first unmanned satellite designed to conduct remote sensing[6] by collecting earth resource data on a

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[5]Originally, the Departments of Agriculture (DOA) and the Interior (DOI) supported the creation of an Earth Resources Observation Satellite (EROS) program to examine the global environment through synoptic views of the earth. In 1968, the DOI requested funding for an EROS program, but the Bureau of Budget (now the Office of Management and Budget, OMB) denied the proposal because the DOI was not authorized to conduct space programs. The OMB did fund NASA to develop the program. Because NASA was prohibited by law from handling the data distribution and services necessary to support the proposed EROS program, a cooperative NASA/DOI plan was devised, and funds were approved in 1969 (EOSAT, May 1989).

[6]Remote sensing satellites detect electromagnetic energy from the earth. Everything in the environment emits or reflects energy. The intensity pattern of each object's emittance or reflectance gives it a unique signature. This signature can also indicate the object's density, surface texture, moisture and other physical and chemical properties. By assigning arbitrary colors to different

systematic, repetitive, multispectral basis. ERTS-1 served its experimental purpose and in January 1975, prior to the launch of ERTS-B, NASA changed the name of the program from ERTS to Landsat,[7] and ERTS-1 was renamed Landsat-1 (Geodynamics, 1990).

Five Landsat satellites have been launched[8] with Landsat's-1, -2, and -3 having been decommissioned, and Landsat's -4 and -5 already exceeding their operational life expectancies (Geodynamics, 1990).

Landsat's -1 and -2 were identically configured, with each carrying a three-channel Return-Beam Vidicon (RBV)[9] and a four-channel Multispectral Scanner (MSS)[10] (Geodynamics, 1990), with a spatial resolution of 80-meters (EOSAT, May,

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frequencies, it is easier to obtain information on vegetation type, mineral content of rock, or the sediment depositing in waterways. (Hughes, 1992)

[7]ERTS was renamed Landsat to emphasize its utility for remote sensing of land as opposed to the atmosphere and oceans (Radzanowski, 1991).

[8]See Appendix B for Landsat spacecraft details.

[9]The RBV is a framed-imaging device which acquires scenes sequentially along the orbit track, recording electromagnetic energy reflected from the earth's surface (Geodynamics, 1990).

[10]The MSS uses an oscillating mirror to scan the earth's surface. A series of 24 detectors record solar energy reflected from the ground and convert it into electronic signals, or digital numbers (DN's), representing brightness values (Geodynamics, 1990). On Landsat's -1 and -2, the MSS collected data by recording reflected light in four different spectral bands (Hughes, 1992). Bands 4 and 5 correspond to the green and red visible regions, while Bands 6 and 7 correspond to the near-infrared (IR) region (Geodynamics, 1990).

1989). A thermal IR band was added to the MSS on Landsat-3. This band failed shortly after launch, so limited data was acquired (Geodynamics, 1990).

A. THE CARTER ADMINISTRATION'S INFLUENCE ON THE LANDSAT PROGRAM

Throughout the 1970's, NASA continued to operate the Landsat program as high-tech experiments (EOSAT, Landsat's Anniversary, 1992).

In 1979, President Carter established a Space Policy Review Board to provide a plan for development of the Landsat program. Based on the Board's finding, President Carter released Presidential Directive 54, which recommended the following:

- Transfer of Landsat operations from NASA to the NOAA, because NASA is a research and development agency and not an operational agency.
- Development of a long-term, operational system with four additional satellites beyond Landsat -3.
- Development of a plan for eventual transition of the Landsat program to a private sector operation.
- Increased fiscal responsibility on the part of the data users, to reflect the actual cost of system operations rather than only materials/reproduction costs (Radzanowski, 1991; and EOSAT, May 1989).

The private sector, under this Directive, was expected to assume ultimate responsibility for operating the system once a commercial market for the data developed (Radzanowski, 1991). This was to be a phased process under Presidential

Directive 54, leading to commercialization in the 1992 time period (EOSAT, Landsat's Anniversary, 1992).

B. THE REAGAN ADMINISTRATION'S INFLUENCE ON THE LANDSAT PROGRAM

In 1981, President Reagan accelerated the commercialization of the Landsat program when he authorized the Civil Operational Remote Sensing Satellite Advisory Committee (CORSSAC), under the Department of Commerce (DOC), to evaluate options related to commercializing the Landsat program (Radzanowski, 1991; and EOSAT, Landsat's Anniversary, 1992). The Cabinet Council on Commerce and Trade (CCCT) was also asked to recommend options for Landsat commercialization (Radzanowski, 1991). After deliberating on Landsat, CORSSAC found among other things, the following, in November 1982:

- The commercial market for Landsat data was underdeveloped because the Government had an experimental program which did not provide data operationally;
- The government had no agenda to develop commercial markets for the data;
- At least two additional satellites beyond Landsat 5 would be required to transition the program to operational status;
- Landsat's -6 and -7 would have to be supported by the government to develop the commercial market for the data;
- Successful commercialization of the Landsat program should be done gradually, so as not to adversely affect the already developed commercial markets;

- Maintain an aggressive program of research in sensor and platform technology to ensure U. S. leadership in the world market;
- The operational data sales from the weather satellites could sustain the gradual commercialization of the Landsat program;
- A lack of understanding of the public good of Landsat in the executive branch at the OMB level, and above (Radzanowksi, 1991).

According to OMB, government support for the Landsat program would end with Landsat-5, and funds for Landsat's -6 and -7 were cut in 1981 (EOSAT, May 1989). In 1983, OMB instructed federal agencies to include budget requests for Landsat data fees in their budgets (EOSAT, May 1989). Before 1983, U.S. government agencies had paid no fee or only a reproduction fee for Landsat data products (EOSAT, May 1989). In early 1983 the CCCT recommended, as had CORSSAC, transfer of both the Landsat program and operational weather satellites to the private sector (Radzanowski, 1991). Under this program, financial returns from the weather satellites were expected to support Landsat costs until the program could become self-sufficient (Radzanowski, 1991). Congress disagreed with this proposal because it felt that with 95 percent of weather data used by government agencies, the weather satellites lacked a private market sector (Radzanowski, 1991).

Congress did however, support the transfer of the Landsat program to the private sector and in July 1984, passed the

Land Remote Sensing Commercialization Act (P. L. 98-365) (Radzanowski, 1991). The 1984 Act did the following:

- Authorized DOC to license private remote sensing space systems that comply with the provisions of the Act;
- Required operators to make Landsat unenhanced data available to all users on a nondiscriminatory basis. This was an extension of existing U. S. "open skies" policy;
- Required DOC to maintain a government archive of land remote sensing data (Radzanowski, 1991).

The Act provided for continuity of the Landsat program after the Landsat-5 mission and the U. S. government would retain ownership of all satellites and data from those satellites (EOSAT, May 1989).

The Reagan Administration's rejection of Presidential Directive 54, which called for a gradual transition to a private sector-operated program for the government, appears to have been pushed well before the Landsat program was financially secure in its future.

C. LANDSAT - TROUBLED TIMES

The Earth Observation Satellite (EOSAT)[11] Company won the competitive bid for a 10-year contract to commercialize the Landsat satellite remote sensing program and was subsequently awarded the contract in September 1985 (EOSAT: Catalog of

[11]The EOSAT Company is headquartered in Lanham, Maryland and was formed as a joint venture between Hughes Aircraft Company (now owned by General Motors) and RCA (now owned by General Electric) (EOSAT: Catalog of Products and Services; and Radzanowski, 1991).

Products and Services). EOSAT was originally responsible for marketing and distributing existing Landsat data, operating Landsat's -4 and -5 under contract to the government, and building two new satellites (Landsat's -6 and -7), including necessary ground systems (Radzanowski, 1991).

According to the contract, the government would continue funding the operations of Landsat's -4 and -5 through their life times, and would provide the satellite hardware and ground systems for Landsat's -6 and -7 (EOSAT, May 1989). Because the market for remote sensing data was, in 1985, considered underdeveloped, the U. S. government agreed to provide $250 million over a five year period to subsidize commercialization of the Landsat program (Radzanowski, 1991).

However, shortly after the contract signing, funding for the development of Landsat's -6 and -7 was eliminated from the federal budget. In a revised contract in April 1988, partial funding was granted to restore continued Landsat-6 development. (EOSAT, May 1989)

Since 1985, the battle to subsidize and fund the Landsat program has gone on between Congress, NOAA and EOSAT (Radzanowski, 1991).

In 1988, NOAA had not anticipated Landsat's -4 and -5 operating beyond 1987 and pointed out that it had no commitment to fund the Landsat program after Landsat's -4 and -5 design life expired. Therefore NOAA did not request any operations funding for the Landsat program for fiscal year

(FY) 1989. Subsequently, Congress appropriated funds for NOAA to cover Landsat operations for the first half of 1989. In early 1989 NOAA said that it had no funding available for Landsat operations after 1 April 1989, and told EOSAT to turn off the Landsat satellites. (Radzanowski, 1991)

Congress and the White House were concerned with the lack of funding for the Landsat program, so the National Space Council developed an interim funding plan in March 1989. The plan allowed Landsat operations to continue through the end of FY1989 by getting DOD, DOI, and DOA, all of whom use Landsat data, to provide money to NOAA for the Landsat program. (Radzanowski, 1991)

For FY1990 and 1991, NOAA again did not request any funding in support of Landsat-4 and -5 operations. Again Congress appropriated money for Landsat operations for the first half of those two years, and agencies such as DOD, DOA, DOI and NASA provided funds for the remainder of those years (Radzanowski, 1991). In 1992, National Space Policy Directive 5 (NSPD 5)[12] overturned the Land Remote Sensing Commercialization Act of 1984 and directed NASA and DOD, along with other government agencies, to realign the future of the Landsat program.

[12]See Chapter VI for further discussion of NSPD 5.

D. LANDSAT'S -4 AND -5

Landsat's -4 and -5 were launched in 1982 and 1984, respectively and remarkably continue to operate today (EOSAT, Landsat Spacecraft Data Sheet, 1991). Both are equipped with the MSS instrument, which was on the first three Landsat satellites, and the Thematic Mapper (TM)[13] sensor (EOSAT Landsat's Anniversary, 1992). Landsat's -4 and -5 have no onboard tape recorders, and therefore all data collected must be downlinked directly to one of 16 ground receiving stations world-wide,[14] or relayed through the Tracking and Data Relay Satellite System (TDRSS)[15] (Geodynamics, 1990). Landsat data is either relayed through the TDRSS, or when the satellite footprint is within range of the ground receiving station, directly downlinked to the ground receiving station at White Sands, New Mexico (Geodynamics, 1990). From White Sands, the

[13]TM is an advancement over the MSS, including higher image resolution and more distinct spectral separation (Geodynamics, 1990). TM uses a scanner mirror that rocks from side to side seven times per second. By deflecting light from the ground into detectors, the mirror scans the scene below in a series of parallel swaths (Hughes, 1992). The TM collects data simultaneously in seven spectral bands (as opposed to four bands in the MSS) covering portions of the visible; near-, mid-, and shortwave IR; and thermal regions. Band 6, which is the thermal band, has a spatial resolution of 120-meters, while the others have a spatial resolution of 30-meters (Geodynamics, 1990).

[14]See Appendix C for Landsat ground station coverage.

[15]TDRSS consists of three relay satellites in geostationary orbits: TDRSS-4 (East), over the Atlantic Ocean off the northeast coast of Brazil; TDRSS-3 (West) over the Pacific Ocean southwest of Hawaii and east of the Gilbert Islands; and TDRSS-1, in a 79 degree West orbit, where it serves as a backup to TDRSS-3 and -4 (Geodynamics, 1990). See Appendix D for an example of TDRSS.

data is retransmitted to Greenbelt, Maryland (Geodynamics, 1990). With EOSAT's new ground receiving station near Norman Oklahoma, now open, Landsat data may be received there soon (EOSAT, Spring 1992).

Landsat TM and MSS data are available in two forms; digital and photographic. Digital data is the most versatile as it can be manipulated and analyzed by computer programs. The use of digital data does, however require an investment of equipment and trained personnel. All Landsat products are corrected for radiometry and geometry. (EOSAT; Catalog of Products and Services) DOD agencies are required however, to order remote sensing data through the Defense Mapping Agency (DMA) and not directly through EOSAT or SPOT.

E. DEFENSE MAPPING AGENCY

As written in DOD Directive 5105.40, December 6, 1990, Section D.15, the DMA shall "serve as the primary DOD action office for all purchases of Land Remote Sensing Satellite (Landsat) and Systems Probatoire d'Observation de la Terre (SPOT) remote sensing data by the Military Departments and Defense Agencies." (Atwood, 1990). Additionally, section E.2 states that "the Secretaries of the Military Departments, Commanders of Unified and Specified Commands, and Heads of other DOD components shall:" among other things, "Submit all requirements and provide funding to the DMA for Landsat and Spot remote sensing data (Atwood, 1990).

Procurement of remote sensing data through DMA for DOD agencies was originally established because DMA was using the data to update maps and charts. DMA was ordering so much data that it was believed that DMA would be a good go-between for DOD and the remote sensing companies, and that way no one in the private sector would know what DOD was ordering (Lesher, 1992).

Now may be the time to reevaluate the value of DOD procurement of Landsat through DMA. With military requirements for MSI increasing, there may be a more efficient manner of acquiring data. The soon to be established Central Imagery Office (CIO)[16] should play a key role in data acquisition for DOD.

[16] See Chapter VI on discussion of the CIO.

III. PREVIOUS MULTISPECTRAL IMAGERY STUDIES

> Continued availability of LANDSAT-type remote sensing information is essential to satisfy a special set of DOD mission requirements. 1989 DOD position (Landsat Background and Policy Brief, 1992)

A. MULTISPECTRAL IMAGERY 1982 - 1990

Department of Defense interest in MSI began in July 1982, when representatives of the Defense Intelligence Agency (DIA) visited NASA facilities for a demonstration of the Landsat products. NASA provided DIA a digital image processing system and assisted in training DIA personnel on the use of the equipment. At that time, members of the Intelligence Community were asked to participate in a DIA-chaired working group that would investigate future multispectral and multisensor exploitation techniques. In November 1982 the DIA-chaired Multispectral Analysis Working Group (MAWG) held its first meeting. The goal of the group was to keep abreast of future developments in digital image collection, processing, and analysis. (Geodynamics, 1990)

As a result of the interest generated by the MAWG, DIA sponsored two studies. The first, <u>Multispectral Imagery Analysis - Opportunities for Defense Intelligence</u>, December 1983, reviewed civil foreign and domestic imaging systems and assessed their potential to answer intelligence requirements. The second, <u>Multispectral Cueing Study</u>, December 1984,

examined the use of a multispectral system to generate cues by applying automated change detection. (Geodynamics, 1990)

The Multispectral Requirements Evaluation Group (MREG) was formed under the auspices of the Intelligence Community Staff and chaired by DIA. The purpose of this group was to evaluate potential applications of MSI to Intelligence Community information needs. The MREG final report, Multispectral Imagery Requirements, May 1984, identified a wide range of needs that could be satisfied by MSI. (Geodynamics, 1990)

MREG-II was formed in 1985 to evaluate the capabilities of collection systems and to determine which system or combination of systems could satisfy the requirements identified by MREG-1. The final report, Collection Systems Capability to Satisfy Multispectral Imagery Requirements, September 1985, identified a range of requirements that could be satisfied by current and programmed systems, and a second group of requirements that would require new or modified systems. (Geodynamics, 1990)

The Tactical and Military Multispectral Requirements Evaluation Group (TaMMREG) was established in September 1985 under DIA and Secretary of the Air Force sponsorship. It was formed in response to the military, specifically the Intelligence Community's need to determine how commercial multispectral remote sensing systems could satisfy tactical and general military requirements. (Geodynamics, 1990) During 1986 and 1987, TaMMREG supported eight military

exercises. The results of these exercises and other 1986 and 1987 TaMMREG activities are documented in Multispectral Application - A Significant New Resource for Warfighting Planning and Execution, January 1988. Analysis of the evaluations supported the following conclusions:

- Multispectral data adds a unique quality to enhance Intelligence Preparation of the Battlefield (IPB);
- The sooner the data is introduced in the planning stages, the better the use;
- Exposure and experience are the key to field exploitation of the asset;
- Considerable planning is needed when placing multispectral image processing equipment into the field for exploitation purposes (Geodynamics, 1990).

In 1986, Naval Space Command (NAVSPACECOM) initiated its Naval Multispectral Applications and Requirements Study (NMARS) (Bonner, Miller, and Rowan, 1992), which was published in December 1987 and which identified potential applications of MSI to operational forces afloat and ashore (Geodynamics, 1990). Although this study encompassed both Fleet and Fleet Marine Force units, it was not the official position of both services (Bonner, et al, 1992).

As a result of the NMARS, the services acquired and installed MSI processing systems at the following commands for test-beds:

- I MEF - 1st Topographic Platoon;
- II MEF - 2nd Topographic Platoon;

- III MEF - 3rd Topographic Platoon;
- Fleet Intelligence Center Pacific (FICPAC), now JICPAC;
- Fleet Intelligence Center Europe and Atlantic (FICEURLANT), now Atlantic Intelligence Center (AIC) (Geodynamics, 1990).

These systems were state-of-the-art 386 personal computer's (PC's), with MSI software, data input, and hard copy generation capabilities, which were to be utilized for testing and evaluation. Limited training was provided to the sailors and marines who would be required to exploit MSI using these systems. (Bonner, et al, 1992) In fact no training was received by future analysts at FICPAC (Wilcox, 1992).

A Naval MSI Evaluation Project (NMEP) was initiated in 1988 to address some of the recommendations of the NMARS (Geodynamics, 1990). As of April 1990, the NMEP had provided a limited quantity of raw data and value-added products to Navy and Marine Corps requestors, and was establishing a basic MSI softcopy exploitation capability for FICPAC and FICEURLANT. A database has been established to track all requests submitted under this program along with an associated inventory of all MSI data procured. The NMEP is coordinated through the Office of Naval Intelligence (ONI), Imagery Planning Group (Geodynamics, 1990).

B. MULTISPECTRAL IMAGERY DURING DESERT SHIELD/STORM

In August 1990, when Iraq invaded Kuwait, the naval service was not yet ready to fully exploit MSI in support of

our warfighters. As a result, the MSI capability was utilized in a spotty and sometimes disorganized manner during Desert Shield/Storm. (Bonner, et al, 1992)

MSI did, however, provide a number of excellent products in support of Desert Shield/Storm. The Army Space Command, Army Space Institute, and Engineering Topographic Laboratories contributed knowledge, skill, and training to their forces, developing and delivering numerous MSI based maps and images to their deployed forces (Bonner et al, 1992).

"FICPAC developed and distributed an excellent suite of image products in support of the initial deployment of Navy and Marine forces" (Bonner et al, 1992), and continued that support throughout Desert Shield/Storm with updates.
FICPAC was probably the most successful naval intelligence center in its use of MSI, during Desert Shield/Storm (Wilcox, 1992). FICPAC would not have been capable of this support except that two personnel at the command had some on-the-job training and experience in MSI analysis. One was the Division Officer, who had received on-the-job training when he worked in industry, and the other was a Marine Gunnery Sergeant who, through his own initiative, taught himself about MSI on the system at FICPAC.

Soft copy MSI was also used for mission planning for air crews. Marine Air Group 11 (MAG 11) and MAG 13 acquired and utilized MSI soft copy merged with Digital Terrain Elevation Data (DTED) from DMA (Bonner et al, 1992). This data was

exploited on a computerized, interactive mission rehearsal system, allowing pilots to fly their mission on the computer while viewing a three-dimensional display of what they would be seeing during ingress and egress (Bonner et al, 1992).

Because of the lack of trained personnel, the marines from the Topographic Platoons of I, II, and III MEF, did not use their MSI-capable systems during Desert Shield/Storm (Barile, 1992).

With outstanding successes and a few failures of products and imagery derived information from MSI during Desert Shield/Storm, MSI is currently being given much more attention. While MSI obviously has supported national security concerns, it also supports civil and commercial concerns.

C. NATIONAL SECURITY APPLICATIONS

MSI supports national security applications in the following areas:

- Military planning and targeting - trafficability/mobility analysis; ingress/egress route planning; materials identification
- Support to U. S. operational forces - activity indication/camouflage detection
- Broad area search - change detection
- Counternarcotics - airstrip/lines of communications detection; illicit crop detection/yield estimation
- Mapping, Charting, and Geodesy (MC&G) - terrain categorization; near-shore bathymetry; image maps

- Strategic resource production and environmental impacts
- Military-industrial production
- Catastrophe/disaster relief
- Treaty verification/proliferation (Landsat Background and Policy Brief, 1992)

D. DEPARTMENT OF DEFENSE MULTISPECTRAL REQUIREMENTS

The following are requirements for MSI, compiled from Unified and Specified Commands, the different Armed Services, and DOD Science and Technology Intelligence Center submissions. Some commands determined that more than one category was important, so the total does not equal 100 percent. The responses were grouped as percentages and so appear that way:

- Planning and current operations 36%
- Targeting 18%
- MC&G - including hydrography 16%
- Defense-related Science and Technology/Industry 70%
- Counternarcotics 16%
- Treaty monitoring and nuclear proliferation 7% (Landsat Background and Policy Brief, 1992)

DOD MSI requirements also include various spatial resolutions of the imagery depending on the information that will be derived from the imagery. While spatial resolution requirements range from 0.3 - 30 meters (Landsat Background and Policy Brief, 1992), future designers of MSI-capable

systems must keep in mind that one of the main attributes of the current MSI-capable systems, particularly Landsat, is its broad area coverage. High spatial resolution on future systems should not be at the expense of broad area coverage.

E. DEFENSE MAPPING AGENCY (DMA) REQUIREMENTS

DMA and current Landsat capabilities for selected characteristics are compared as follows:

CHARACTERISTIC	DMA REQUIREMENT	CURRENT Landsat
• Resolution	3-5 meters	30 meters
• Stereoscopic Coverage	Yes	None
• Metric Data:		
Positioning Data	GPS	None
Orientation Data	Star Sensors	None

(Landsat Background and Policy Brief, 1992)

1. High Resolution Imagery Requirements

The following are examples of features that require high resolution imagery for identification and attribution to satisfy military requirements:

- Lineal - fences, power lines, hedge rows
- Aerial - dry dock, buildings, bridges, mobile home parks
- Point features - towers, flare pipes, tunnel tubes, wells
- Others - ferry crossings, buoys, anchorage, reef, springs, caves, culverts (Landsat Background and Policy Brief, 1992).

Again, it must be stressed that high resolution of MSI imagery must not be designed into the system at the expense of broad area coverage. There are other systems and capabilities that can be used for point targeting, with tunnel vision, and we must be aware that high spatial resolution should not replace broad area coverage of future MSI systems. The broad area coverage capabilities of Landsat is too valuable to lose on current or future systems.

F. MULTISPECTRAL IMAGERY CIVIL AND COMMERCIAL APPLICATIONS

MSI has been supporting civil and commercial activities for quite some time. As we become more involved in humanitarian assistance and other "non-military" activities, the military may look to MSI for non-traditional military uses. Meanwhile, MSI continues to be used to support the following major categories of civil and commercial applications :

- Environmental monitoring - disaster assessment, oil spills, deforestation, forest fires, flood damage
- Agriculture - famine relief, crop disease
- Forestry - timber management, change detection, acreage statistics
- Land use - water usage patterns, dry land agriculture
- Regional planning - encroachment monitoring, drainage patterns, transportation corridors
- Mapping - remote area mapping, map updates
- Geology - mineral detection, earthquake damage assessment

- Water resources - flood plains, irrigation
- Oceanography - bathymetry, thermal (Landsat Background and Policy Brief, 1992; and Marine Corps Intelligence Center, 1992).

G. MULTISPECTRAL IMAGERY FOR MISSION PLANNING

A survey was conducted by the Cruise Missiles Project Office to determine the applicability of MSI to mission planning for cruise missiles. According to the survey results of 18 October 1991, the utilization of MSI from commercially available satellites as a data source was a system requirement of the Digital Imagery Workstation Suite (DIWS). DIWS should be capable of using MSI as a broad area search tool for the identification of ground areas, which might be considered suitable as Digital Scene Matching Area Correlator (DSMAC) scenes. MSI was evaluated by the Naval Avionics Center (NAC), as a "first look" tool for analyzing the entire target area and categorizing ground features which might be considered suitable for DSMAC scenes. MSI would be used as a preplanning tool to conserve time in higher resolution imagery tasking and to expedite DSMAC scene preparation. (Smith, 1991)

This study indicated that MSI has "excellent potential for use in this specific mission planning application." Further, the study results "highly recommended that the capability to utilize MSI as a data source be incorporated in the DIWS system for the expedition of cruise missile mission planning." (Smith, 1991)

Many studies, evaluations, tests, and exercises, as well as actual combat applications, have been conducted with MSI. The consensus from all these uses is that MSI is a system that continues to offer excellent potential for support of our armed forces, as well as civil and commercial applications. Chapters IV and V offer additional results on surveys conducted by the author. Many of the ideas for MSI applications are the same as those expressed in this chapter. However, additional information, such as timeliness of dissemination and operational security are explored through the responses of operators and intelligence specialists.

IV. OPERATIONAL REQUIREMENTS FOR MULTISPECTRAL IMAGERY

On 5 May 1992, a survey[17] of user requirements for MSI was conducted of the CNO Tactical Development and Evaluation Conference, to determine operators' use and interest in MSI information and capabilities. Results of the 21 survey responses reflected the varying function and focus of the commands represented, including: COMSIXTHFLT, COMTHIRDFLT, COMCRUDESGRU FIVE, COMSURFWARDEVGRU, COMSUBDEVRON TWELVE, COMNAVAIRLANT, COMCARGRU SEVEN, AIRDEVRON ONE, and AIRDEVRON FIVE. Some commands were represented by more than one person, so that command may appear more often than others in the response section.

The survey was conducted to determine: 1) If the respondent was previously aware of MSI capabilities and implications; 2) In what areas of planning the respondent would like to see a more extensive use of MSI; what the respondent would like MSI to do for them; 3) What the respondent views as the most desirable distribution of MSI products and information; 4) What the respondent views as operational security concerns, if a potential enemy can access and exploit information from the commercially available MSI products; 5) What the respondent considers to be the optimum

[17]See Appendix A for survey sample questions.

timeliness in receiving MSI products; monthly updates; daily updates, contingency-driven updates; 6) Additional Comments/Recommendations regarding MSI. Responses will be discussed in this chapter.

A. AWARENESS OF MULTISPECTRAL IMAGERY

Of the 21 respondents, 29 percent had no previous knowledge of MSI. While 71 percent knew something about MSI, the majority appeared to know very little about its capabilities and implications. The questions about MSI capabilities and the responses to these surveys were encouraging and demonstrated that there is an immense interest in MSI by operators. Unfortunately, while many commands and personnel have worked with MSI, it is apparent that the information has not been widely distributed to Fleet users.

B. AREAS OF PLANNING WITH MULTISPECTRAL IMAGERY

The majority of respondents were interested in more extensive use of MSI for shallow water mapping of coastal areas (Boyd, Farrell, Giambastiani, 1992). For naval forces this will probably be the greatest area of use, especially if bathymetric measurements can be used in the future and are accurate. The study of ocean fronts and eddy analysis (Talipsky, 1992), evaluation of water depth, bottom type and topography such as sand, coral and rocks (Boyd, 1992) were all suggested as requirements for MSI. These analyses could all

support contingency planning for Non-combatant Evacuation Operations (NEO) and combatant amphibious operations in the future. While no Special Forces, such as Sea-Air-Land (SEAL) Team members, were included in the surveys, these forces could greatly benefit from the information gained from shallow water MSI data. Water depth and type of beach floor, as well as determination of vegetation along a beach, are all information that can be gleaned from MSI data. Instead of risking lives to scout out an area for a beach landing, land remote sensing systems, which are suited to this type of data gathering, could be utilized. Inshore warfare support teams could also benefit from MSI-derived information.

Interest in shallow water mapping in support of Anti-Submarine Warfare (ASW) and determining shallow water submarine operating areas were also of interest (Dodsworth, 1992) mainly to the P-3 community. Respondents from the P-3 community expressed a desire for this capability, but other ASW communities such as S-3's, H-3's, and SH60's could most certainly benefit as well.

One respondent suggested that anti-mine warfare, which has always been and continues to be a problem for U. S. forces, would also benefit from shallow water mapping (Dodsworth, 1992). Perhaps, mapping of coastal areas could indicate where potential enemies may place mines and help to determine where the U. S. should initially conduct mine clearing or laying operations.

Targeting, strike planning, mission planning, target placement and density of target, and target movement concern the strike aviation community (Cetow, Ogle, Talipsky, 1992). MSI is currently being used for broad area coverage of strike targets so the pilot can get a sense of the overall target area. Landsat resolution currently is not as detailed as other imagery information for target specific planning. Broad area coverage does however, provide information for overall target area or for movement of large amounts of troops, such as across the desert during Desert Shield/Storm.

Strike Rescue or Search and Rescue (SAR) planning were also suggested as requirements of MSI (Dodsworth, Nosenzo, 1992). Unfortunately, planning with MSI would have to be accomplished well in advance of any type of rescue, because of lack of timeliness of current systems. This would present problems though since most SAR should be completed within 30 minutes for increased likelihood of successful operations.

Additionally, threat avoidance and detection of Surface-to-Air Missile (SAM) sites are of interest (Nosenzo, 1992). The concerns again are, can MSI exploit this in a near-real time effort and how timely is the information?

Detection of SCUD land sites and SCUD launchers has become a greater concern (Talipsky, 1992), considering the smaller developing countries we will probably be engaging in the future. MSI was used as broad area coverage to locate SCUD sites in Iraq (Barile, 1992). Concurrent with this thesis

being written, a classmate at the Naval Postgraduate School (NPS) is researching mobile SCUD detection.[18] Unfortunately, he has found that MSI was applied late in the detection of mobile SCUD's during Desert Storm and its effectiveness has not yet been determined (Greenwood, 1992).

COMSIXTHFLT was interested in the use of MSI for counternarcotics operations, specifically the use of port imagery to determine the presence or absence of suspect ships (Talipsky, 1992). MSI can also be used to identify crops and help drug eradication efforts by determine where various crops are grown.

Tomahawk Land Attack Missile (TLAM) environmental planning was another suggested use for MSI (Talipsky, 1992).

Indications and Warnings (I & W) is an area in which one respondent said he would like to see more use of MSI (Tandy, 1992). Perhaps a more timely system in the future will give us greater possibility of use of Landsat and Spot for I & W, but the systems are not timely enough now.

Tactical Aircraft Mission Planning System (TAMPS) and Tactical EA-6B Mission Support System (TEAMS) integration were also suggested (Nosenzo, 1992). Merging MSI with these systems would give pilots an extremely efficient ingress/egress planning system.

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[18]The title of the thesis is Countering Mobile SRBM Threats: Lessons Learned from the Gulf War, by LT Michael D. Greenwood.

COMNAVAIRLANT indicated that Battle Damage Assessment (BDA) capabilities would be a valuable use of MSI (Ogle, 1992). For large targets and complete destruction this may be feasible, but point target weapon delivery and destruction may be difficult to determine.

All this interest in MSI indicates the potential value of the product. Unfortunately, it also indicates some misperceptions of how it currently can be used.

C. DISTRIBUTION OF MULTISPECTRAL IMAGERY

The majority of respondents expressed an interest in distribution of MSI products or information to the user level aboard individual ships or with individual squadrons (Cetow, Dodsworth, Fuller, Kinnane, Nosenzo, Parmenter, 1992). Answers as to the level of distribution varied with the combat situation, whether it was peacetime or whether we were involved in a conflict. For instance one respondent indicated that MSI should be distributed to the national intelligence centers during peacetime and to the Joint Task Force (JTF) during crisis (Tyler, 1992). One problem with this concept is if we are going to train the way we fight, then the MSI products and information need to be distributed to the user during peacetime as well as in wartime.

Other respondents suggested distributing MSI products to Carrier Air Group (CAG) intelligence officers, who then would

distribute the information down the chain of command (Farrell. Schneider, 1992).

Distribution of MSI data to Battle Group Commanders was second to individual users receiving MSI (Ogle, Talipsky, Vaughan, 1992). While this goes a long way in getting the information to the Fleet, MSI products would be better utilized if the user, the intelligence officer or targeteer, were the direct recipient.

Some respondents felt that Numbered Fleet Commanders would benefit the most by receiving the information or products (Boyd, Talipsky, Watras, 1992). While MSI may be useful to these commanders, the intelligence officers and targeteers need the information as well.

D. OPERATIONAL SECURITY CONCERNS

This should be one of the most important concerns to the U. S. While Landsat and Spot information are available to anyone, anywhere in the world, we need to be aware that the information gained by others, especially potential adversaries, could be used against us. Our potential adversaries will likely be collecting information about us, while we are collecting information about them.

Some respondents indicated that our potential enemies will know information about us that we might not want them to know, and that coverage cannot be denied them (Boyd, Tyler, 1992). Additionally, concern for improved resolution and timeliness

could present problems if enough real-time data is available to our potential adversaries. The COMSURFWARDEVGRU respondent mentioned that if the imagery product is timely and can permit picking out ships in "mid-ocean through wake patterns," then access to Landsat or Spot by potential adversaries poses a greater threat than if the imagery received can determine "two weeks after the fact that the Norfolk piers are empty." (Roberts, 1992)

To counter our enemy's ability to gain access to MSI products, it was suggested that allied countermeasures be developed to deny a potential enemy access during a crisis period (Watras, 1992). This was practiced with Spot and Landsat data during Desert Storm. Another recommendation to discourage a potential adversary from gaining access to MSI products and information about the U. S. could include some type of deception technique to alter the information an enemy may receive (Tyler, 1992).

If access is not denied to our adversaries during crisis and maybe even during peacetime, and the resolution and timeliness improve, one respondent felt that significant intelligence against the U. S. may be gained by an adversary (Talipsky). Such information might introduce new vulnerabilities to our surface combatants and non-combatants (Brunner, 1992). Another felt that because of this access, the U. S. may be more prone to terrorist attacks (Ogle, 1992). If a country has enough money available to gain access to the

MSI information and can pay to have trained personnel exploit it, then the MSI information could more easily be used against us.

One respondent felt that only sophisticated countries or threats would use this type of information against the U. S., since much of the information that can be gained about the U. S. is already available from other less expensive, open sources (Tandy, 1992). This may not be true, however, of other countries. Some of the countries we may be supporting or fighting against in future operations may not have maps or charts of particular areas available.

E. OPTIMUM TIMELINESS

Timeliness, as with all intelligence information, is extremely important where imagery is concerned. Depending on the situation some respondents had more than one requirement for MSI timeliness. One respondent summed up what others touched on and that is that optimum timeliness depends on:

> ... the threat posture of the targeted location. As inevitable strike dates grow closer, the system must be able to keep up with the demand. (Kinnane, 1992)

Of the respondents, 43 percent felt that daily updates were necessary for planning. This would only be useful if Landsat and Spot information were available on a more timely basis.

Requirements for contingency driven updates were also high, with 38 percent of respondents requiring this

timeliness. If a crisis or contingency does take place, then immediate, 24-hour or less, updates would be required.

Monthly updates were recommended for long term strike planning (Brunner, Dodsworth, Farrell, Parmenter, Thompson, 1992). This is probably the most feasible current use of MSI data considering the timeliness, or lack thereof, of current Landsat and Spot products. While these updates could be used for long term planning, one respondent would like to see MSI being used for historical studies as well (Tyler, 1992).

F. ADDITIONAL COMMENTS/RECOMMENDATIONS

As with all information intended for direct support of the Fleet, the question always arises as to distribution of information to the user. Fleet Imagery Support Terminal (FIST) transmissions were suggested as a means of transmitting MSI to the Fleet (Talipsky, 1992). Additionally, some type of commercial video image transmission system was suggested (Talipsky, 1992). Transmission of MSI to the Fleet will require a great deal of research since transmission of MSI data will probably take a lot longer than what is transmitted on the current military systems today.

One respondent recommended that Landsat and Spot products be available without DoD users having to go through the DMA to purchase MSI products (Dodsworth, 1992). Another respondent recommended that personnel be trained to exploit and understand MSI and the products that can be used from these

systems. She also suggested that a deployable pool of trained photographic interpreters be available to the Fleet for the near term (Tyler, 1992). These ideas will both be discussed further in chapter VI.

V. INTELLIGENCE REQUIREMENTS FOR MULTISPECTRAL IMAGERY

A survey was conducted of the Naval Intelligence Training Council (NITC) Conference on 13 May 1992 to ascertain what requirements the Intelligence Community has for MSI information and products. Results of the 18 surveys were as varied as the commands that were represented, including: COMTHIRDFLT, COMNAVSURFPAC, COMNAVSURFLANT, COMNAVAIRPAC, COMNAVAIRLANT, COMCARGRU ONE, JICPAC, CENPROGFAC, DIA-DET-2, FITCPAC, VT-10. Many respondents answered questions with more than one answer. So, while it may appear that there are many more answers than participants, the answers are not mutually exclusive of each other. The survey was identical to the one given to the CNO Tactical Development and Evaluation Conference and was conducted to determine: 1) If the respondent was previously aware of MSI capabilities and implications; 2) In what areas of planning the respondent would like to see a more extensive use of MSI; what the respondent would like MSI to do for them; 3) What the respondent views as the most desirable distribution of MSI products and information; 4)What the respondent views as operational security concerns, if a potential enemy can access and exploit information from the commercially available MSI products; 5) What the respondent considers to be the optimum timeliness in receiving MSI products; monthly updates; daily

updates; contingency-driven updates; 6) Additional Comments/Recommendations. The responses are discussed in this chapter.

A. AWARENESS OF MULTISPECTRAL IMAGERY

Of the 18 respondents, 17 percent did not know anything about MSI and its implications. While 83 percent knew something about MSI, some only knew a limited scope of MSI capabilities and implications.

B. REQUIREMENTS FOR MSI IN PLANNING

> We need to understand exactly what MSI can do for us. Any warfare area that can be supported is a target for support. Smart folks need to study this sensor and sell it applicably. (Costarino, 1992)

The majority of respondents were interested in MSI for intelligence support to amphibious operations (Kessler, McKeldin, Olsen, Thomas, Sullivan, 1992). One respondent believed that MSI has its greatest potential in amphibious planning and beach studies (McKeldin, 1992). He also accurately states that these studies were of great value to U. S. Marines during Desert Shield/Storm contingency planning (McKeldin, 1992). Several respondents mentioned that MSI would be extremely useful in supporting contingency operations (Kelly, Nicholson, Sullivan, 1992), and that if it were more available and timely, it could more successfully support short notice contingencies for amphibious assaults (Sullivan, 1992). Support with MSI information and products to the CJTF and

component commands would be beneficial during contingencies (Kelly, 1992).

Use of MSI for targeting and strike warfare is a requirement by some respondents (Hayes, Kelly, Nicholson, Nikola, Stefansky, 1992). One respondent mentioned that although he did not know much about the potential use of MSI in targeting, it seemed to him that it could be very useful if the timeliness of the products could be improved. He suggested the use of non-commercial satellites for MSI collection (Nicholson, 1992). Another respondent felt that, while MSI could be used for targeting, its area coverage is so broad that it would have limited application for targeting (Kelly, 1992). This is currently true about Landsat and Spot systems.[19] Another respondent felt that targeting intelligence for ATTG's, developed by the Joint Intelligence Centers, would benefit from the use of MSI (Nikola, 1992). One respondent mentioned that MSI products were widely used during Desert Shield/Storm for strike route planning and that this imagery provides strike mission planners with "important topographical information currently lacking in Defense Mapping Agency products." (Stefansky, 1992) Mobile targeting is another area where more extensive use of MSI was suggested (Olivier, 1992).

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[19] See Chapter II for Landsat resolution characteristics, and Chapter VII for Spot resolution characteristics.

Mine detection and the use of MSI for the placement of mines was also suggested (Caldwell, 1992). One respondent mentioned that the VP community should be aware of the capabilities for mine-laying missions of Maritime Patrol Aircraft (MPA) (Jacobson, 1992).

Detection of maritime pollution was suggested as a future requirement of MSI (Marshall, 1992). This may be required more and more, since we may be drawn into defeating environmental terrorism in future operations, as we did with Iraq and the oil-well fires and oil spill during Desert Shield/Storm.

The use of MSI for counter narcotic operations is a requirement (Marshall, Nicholson, 1992), and MSI is probably already being used for specific crop detection (Nicholson, 1992).

MSI for Indications and Warnings (I & W) would be beneficial according two respondents (Kelly, Kessler, 1992). This would be particularly true if MSI information and products were more timely (Kessler, 1992). Perhaps expert daily analysis of MSI would benefit pre-exercise and pre-operational planning (Kessler, 1992).

Terrain analysis for Intelligence Preparation of the Battlefield (IPB) was a requirement by one respondent (Kelly, 1992), as was construction analysis of buildings and bunkers, especially from a targeteer's point of view (Olivier, 1992). Coinciding with construction analysis, is the requirement for

land remote sensing systems to detect camouflage and deception of potential adversaries (Caldwell, Nikola, 1992). One respondent would like to see an extensive use of MSI against camouflage and deception which has been used to counter aerial photographic reconnaissance (Nikola, 1992).

Detection of oceanic fronts and patterns was expressed as a requirement for MSI (Marshall, 1992).

Current MSI sensors are ideal for broad area coverage, which continues to be a requirement for MSI products (Hayes, Kelly, Stefansky, 1992). These land remote sensors can be used to image broad areas not covered by other imagery sources, and this respondent felt that we need to develop MSI interpretation expertise in the fleet to interpret those broad areas (Stefansky, 1992). The broad area coverage capability could be used in "one-to-one integration with optical imagery." (Hayes, 1992) MSI should be used in conjunction with and to augment existing sensor systems to aid imagery analysts in building target folders (Koualerzle, 1992).

C. DISTRIBUTION OF MSI TO THE FLEET

Fifty-six percent of the respondents felt distribution of MSI products and information should be to the lowest level possible, such as to ship, squadron, and Marine Expeditionary Unit (MEU) intelligence officers and planners. The majority of these respondents felt that this information would be most valuable to the user aboard ship, particularly aboard aircraft

carriers (Caldwell, Hayes, Kessler, Olivier, 1992). One respondent felt that if intelligence officers and specialists could read and interpret the product that this would "greatly enhance [the effectiveness of] pre/post brief intelligence to aviators." (Kessler, 1992) Another respondent, who required distribution of MSI to the "furthest most regions," would like to see more development of MSI "to CD-ROM's for individual ships and commands for strike warfare" use (Nikola, 1992). One other respondent stated that MSI makes "pretty pictures for ships, squadrons, etc. but they don't need them unless it's missiles on the target time." (Nicholson, 1992) While this may be true, some pre-planning must be done with MSI data if it is to be incorporated into any mission planning.

Individual ships such as LHD's, LHA's, LPH's and flag-equipped LPD's should receive MSI material according to one respondent (McKeldin, 1992). Some respondents recommended that MSI products be disseminated to MEU's and tactical amphibious squadrons (McKeldin, Sullivan, 1992).

Several respondents felt that distribution of MSI to the carrier air wing would be best (Nicholson, Olivier, and Stefansky, 1992). One of these respondents suggested that MSI information could best be used at the carrier air wing level for "briefing, I&W, or targeting, as appropriate." (Nicholson, 1992) Another respondent felt that distribution of MSI to the air wing level was important because CAG is the Strike Warfare Commander and the "in-depth end game strike planning takes

place at this level." (Stefansky, 1992) Additionally, carrier air wing reorganization calls for "establishment of a targeteer/BDA expertise on his staff." (Stefansky, 1992)

Forty-four percent of the respondents stated that MSI should be disseminated to the carrier battle group staff. One respondent felt that MSI information and products should be disseminated to the Battle Group Staff, but in a limited amount (Kelly, 1992), because carriers and ARG's should be the main recipients. Meanwhile, others suggested that MSI be used for strike planning (Jacobson, 1992) at the CVBG level or in CONOPS support packages and SAO packages to augment other information in those packages (Costarino, 1992).

Two of the respondents recommended that MSI be distributed to ARG Staffs, especially for amphibious warfare planning (Jacobson, Kelly, 1992). Others felt that PHIBGRU or PHIBRON Staffs should be recipients of MSI data (Olsen, Sullivan, 1992).

A limited amount of MSI information should be received at Numbered Fleet or JTF Staffs (Caldwell, Jacobson, Kelly, Olsen, 1992). These staffs could use the information for build-up to a crisis response and during the crisis or any contingencies that may arise (Jacobson, 1992).

Distribution of MSI should also include the Joint Intelligence Centers, i.e. JICPAC, AIC (Jacobson, Koualerzle, Marshall, 1992). Hardcopy and softcopy products would both be useful in augmenting existing sensor systems and aiding

imagery analysts in all-source fusion analysis (Koualerzle, 1992).

D. OPERATIONAL SECURITY REQUIREMENTS

While operational security is paramount to national security, there may be a problem with potential enemies gaining access to information about our forces or country from land remote sensing systems. One respondent suggested that the element of surprise may be lost, if operational security is not protected (Kessler, 1992). A couple of respondents mentioned that we cannot keep commercially available information and products from our potential adversaries. We must instead, be better and smarter at using MSI information than our adversaries (Costarino, McKeldin, 1992). We need to concentrate our strengths in "processing, distributing, and fusing information" to gain the lead in MSI exploitation over our potential adversaries (Costarino, 1992). We need to know "our own vulnerability to this system and then how to correct the problem." (Thomas, 1992)

One respondent mentioned that operational security is of "no significance" on a daily basis as far as the fact that the U. S. uses MSI, but it may become a concern if the potential enemy determines how we intend to use it in a particular operation (Caldwell, 1992). Another felt that the U. S. would "want to keep a lid on" how we use MSI in future operations, including strike warfare (Nikola, 1992).

One area that may be a potential problem in using MSI, is in counter-narcotic operations. Some respondents felt that narcotics operations may be hampered if drug crop growers can hide their crops in some way, thus countering these systems. (Kelly, Kessler, 1992)

Another potential problem could arise for U. S. forces deployed overseas where land remote sensing collection could locate them in foreign ports or on foreign bases (Kelly, 1992). One suggestion to counter imaging of bases in our own country is to place restrictions, which must be enforced, on imaging of areas near our military installations (Olivier, 1992). With commercial satellite systems such as Spot and Landsat it is virtually impossible to impose such restrictions. If we can determine what our potential enemies are looking at, that may help us determine their intentions, and we may be able to counter them (Nicholson, 1992). Several respondents suggested ways to counter our potential adversaries' ability to use MSI against us. We must become experts in MSI capabilities and implications before we can counter with camouflage, deception and misinformation (Stefansky, 1992). Once we understand MSI capabilities we must consider developing a policy of cover and deception (Hayes, 1992). Measures to alter MSI signatures were also suggested as a means for giving the potential enemy misinformation (Marshall, 1992).

Finally, one respondent felt that commercially available MSI products should be made illegal (Sullivan, 1992), probably because of many of the above cited reasons.

Proliferation of land remote sensing systems from other countries was also of concern to OPSEC (Elder, 1992). Some countries, such as the Former Soviet Union (FSU), have a proliferation of these systems and we should be concerned with to whom these systems are being sold to obtain hard currency to resolve their severe economic crisis (Elder, 1992).

E. TIMELINESS OF MSI DISTRIBUTION

Timeliness of MSI products and information is crucial if it is to be used as an intelligence tool. This is supported by the fifty-six percent of the respondents who agreed that optimum timeliness for receipt of MSI products will be contingency-driven. Some respondents recommended that MSI be a part of the original targeting package given to deploying ships and that these packages be augmented with MSI as contingencies or crises arise (Costarino, Olivier, 1992). While MSI information and products should be driven by the contingency, JIC's, AIC and Naval Strike Warfare Center (NSWC) "should know CONOPS requirements and thus can provide guidance and subsequent distribution to the fleet." (Nicholson, 1992) A couple of respondents suggested that a monthly updated baseline of data for "areas where significant changes occur regularly" (Hayes, 1992) or for "routine, mundane targets and

geographic areas" (McKeldin, 1992) would be acceptable as long as the system can "flex to increased requirements to support a contingency operation." (Hayes, 1992) Contingency-driven updates would be appropriate to "determine changes between imagery" (Marshall, 1992) such as for "new construction and in response to specific tasking" (Caldwell, 1992) and in support of such operations as "Sharp Edge, Eastern Exit and Desert Shield/Storm." (McKeldin, 1992) One respondent suggested that recurrence of imaging be conducted monthly for drug crops and every six months to a year for urban areas, depending on construction and other activity (Elder, 1992). Another suggested that updates for exercises be every 30 days, but within 48 hours for contingencies (Sullivan, 1992).

Some respondents felt that daily updates, depending on what part of the world we are concerned with, would be most appropriate. One respondent mentioned that "during crises, daily updates would be ideal," and that "MSI should be digitized for dissemination." (Stefansky, 1992) As was suggested by one respondent, these daily updates, particularly during a contingency, should be disseminated to the CJTF and ashore intelligence centers (Jacobson, 1992).

As previously suggested, the more routine targets should be updated monthly by MSI products. Additionally, one respondent suggested that initial distribution of MSI data should take place prior to crisis planning, then that information should be updated monthly (Kelly, 1992). Another

suggested that monthly updates should go to the JIC's and AIC (Jacobson, 1992).

One respondent recommended quarterly updates only if "major upgrades or degradations" were apparent (Nikola, 1992).

F. ADDITIONAL COMMENTS/RECOMMENDATIONS FROM RESPONDENTS

Future uses of MSI products was what interested most of the respondents. One was interested in how MSI information can be further utilized for strike planning (Nikola, 1992). Another suggested that specific examples of MSI products and information should be provided to potential recipients, i.e., Fleet Commanders and aircraft carriers (Caldwell, 1992), while another recommended that carriers and carrier air wings "must be able to receive MSI [data] via new imagery support systems in order to support CONOPS." (Olivier, 1992) One respondent pointed out that there are many professional intelligence analysts who do not understand what MSI can do for them, and he suggested that the "Science and Technology community needs education" on MSI (Marshall, 1992), if we are to use it to its fullest capabilities in the future.

VI. WHAT DOES THE FUTURE HOLD FOR MULTISPECTRAL IMAGERY?

> For global research, environmental management, and national security purposes, in particular, continuation of the Landsat program through the 1990's will be mission essential. (H. R. 3614, 1992)

For the past ten years numerous studies have been conducted to determine what the requirements and applications are for MSI in DOD, and in the naval service in particular. Landsats-1 through -5 have supported many of the requirements of the civil, commercial, and military sectors of our society. The future of Landsat looks bright if DOD continues to pour money into the capabilities of new systems.

A. LANDSAT 6

The launch of Landsat-6 in early 1993 will mark the beginning of the new era in commercial remote sensing (EOSAT, Landsat's Anniversary, 1992). Follow-on systems such as Landsat-7, which will be jointly operated by DOD and NASA, will continue to enhance U. S. remote sensing capabilities and keep the U. S. in the fore-front in commercial land remote sensing. Meanwhile, foreign land remote sensing systems will continue to compete with Landsat for commercial sales and possibly will affect our national security.

After an 18-month shutdown, due to funding uncertainty and political reasons, EOSAT restarted its development work on Landsat-6 in April 1988 (Radzanowski, 1991). Development of

Landsat-6, under construction by General Electric Astro-Space, is estimated by EOSAT to cost roughly $240 million (Radzanowski, 1991).

Landsat-6 will carry the Enhanced Thematic Mapper (ETM), which is the next generation sensor with multispectral capabilities identical to the Thematic Mapper (TM) onboard Landsats-4 and -5 (EOSAT, Landsat's Anniversary, 1992). The ETM will provide 30-meter ground resolution in seven spectral bands with the addition of a panchromatic band[20] with 15-meter spatial resolution (GE Astro Space). Because Landsat-6 will have the same spectral capabilities as Landsats-4 and -5, data continuity is assured (EOSAT, Landsat's Anniversary, 1992). EOSAT was also considering a Sea-Wide Field-of-View Sensor (SEA-WIFS) to provide ocean color and temperature information, but due to spacecraft cost considerations, the instrument was not included on Landsat-6 (Radzanowski, 1991). Additionally, two tape recorders will store image data when Landsat-6 is not within range of a ground station for later transmission, when it is within range of a ground station (GE Astro Space).

EOSAT will continue as the contractor to the Landsat-6 system and will cover the costs of operations and continued marketing of unenhanced data (Radzanowski, 91). Landsat-6

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[20]This is a black and white image.

will be launched by a Titan II rocket and is expected to have a five year design life (GE Astro Space).

The ground station in the U. S., which has just opened this year near Norman, Oklahoma, was transferred from EOSAT-controlled, government-owned equipment to being completely controlled by privately-owned equipment with EOSAT revenues. All data acquisition, satellite control, and ground equipment maintenance will be EOSAT's responsibility and at EOSAT's expense (EOSAT, Spring 1992). Norman's mid-continent location will provide real-time direct downlink capabilities for image acquisitions over the entire continental U. S. The new station will also receive international imagery data stored on Landsat-6's on board recorders (Radzanowski, 1991).

B. LANDSAT-7

> For more than a decade, Landsat has been surrounded by a cloud of uncertainty that has harmed market growth and stigmatized the program. - Representative Brown (Asker, 1991)

After twenty years of being shuffled from one government agency to another and then to the private sector, the Landsat program is being shuffled again, back to the government. In February 1992, President Bush signed National Space Policy Directive 5 (NSPD 5) defining the roles for NASA and DOD in the future of the Landsat program. The Directive also clarifies the roles of the Departments of Commerce, Energy, and the Interior in connection with Landsat (Bush, 1992). The

Directive contains strategy and guidelines similar to two bills that were to be proposed to Congress. The two bills, H.R. 3614, National Landsat Policy Act of 1992 (Brown Bill), and S. 2297, Land Remote Sensing Policy Act of 1992 (Pressler Bill), proposed sweeping reforms in the Landsat program (Asker, July 13, 1992).

1. National Landsat Policy Act of 1992 (Brown Bill)

Representative George Brown, Jr. (D-California), chairman of the House Science, Space and Technology Committee, introduced legislation concerning Landsat in October 1991 (Asker, 1991). The legislation, which was approved by the Committee, repealed the Land Remote-Sensing Commercialization Act of 1984. It would also shift Landsat oversight from NOAA to a Joint Program Office (JPO), to be administered by NASA and DOD (EOSAT, Winter 1991).

Historically, no federal agency has found the Landsat program important enough to want to manage it or pay for it, although many departments use it extensively (Asker, 1991). DOD is the largest user of MSI, particularly following its extensive use of Landsat imagery during Desert Shield/Storm. The temptation now is for policy makers to make DOD pay for Landsat, but some fear that may lead to restrictions on access to remote sensing data (Asker, 1991). Additionally, if sole control of the Landsat program is given to DOD, this would greatly alert international perceptions of the program, which

was specifically initiated as a demonstration of the U. S.'s commitment to the peaceful use of space (Brown,1992). Consolidating military and commercial requirements, funding, and management responsibilities into a JPO would be the most logical management of the Landsat program. Therefore, the solution may be in Representative Brown's suggestion that the JPO be comprised of DOD and NASA.

The National Space Council endorsed the concept of the JPO and announced that the Administration would seek funds in FY93 to build Landsat-7 (EOSAT, Winter 1991). This joint management would include acquisition and operation of a Landsat-7 satellite "as quickly as practicable which is, at a minimum, functionally equivalent to the Landsat-6 satellite" (H. R. 3614, 1992). The projected operating life of Landsat-6 requires that construction of Landsat-7, which has been postponed several times by federal budget-makers, be accelerated to avoid creating a gap in Landsat data coverage (EOSAT, Winter 1991).

The Brown Bill would also offer a two-tier pricing system, one for commercial enterprises and another for government, academics, and other domestic non-profit users (Asker, 1991). Non-profit users in the U. S. would pay only the marginal costs of acquiring and distributing Landsat data, while all other buyers would pay the full commercial price (EOSAT, Winter 1991). In the recent past, use of Landsat imagery by non-profit users has dropped dramatically because

prices rose after Landsat was turned over to a private contractor. Researchers are paying more, primarily because government subsidies of their Landsat work, which were often not readily apparent before commercialization, have disappeared (Asker, July 13, 1992) In 1985, prior to the EOSAT contract, NOAA charged $4,400 for a digital Thematic Mapper data scene (Radzanowski, 1991). Under EOSAT, the price fell to $3,300 but has recently risen back to $4,400 (Radzanowski, 1991). EOSAT's president, Arturo Selvestrini, maintains that the true costs of operating Landsat have come down under private management. The real cost of Landsat digital products is 21 percent lower in 1992 than in 1985 (Asker, July 13, 1992). While this two-tier system may not be a problem as long as the government is running the show, there may be problems with this pricing scale if a private company is contracted for Landsat operations and tries to make a profit (EOSAT, Winter 1991). EOSAT company's then interim president, Jay Buckley, said that the proposed legislation provides a basis to negotiate a stable future for Landsat (Asker, 1991). There may also be a problem with policing who is a non-profit agency and who is not.

2. Land Remote Sensing Policy Act of 1992 (Pressler Bill)

Senator Larry Pressler (R-South Dakota), the ranking Republican on the Senate Science, Technology, and Space subcommittee, proposed legislation similar to Representative

Brown's proposal, but with one major difference. Instead of a two-tiered system, Pressler proposed that all Landsat imagery be sold to anyone for the marginal cost of producing the pictures (Asker, July 13, 1992). This of course could only happen if the government runs the show and does not plan to make any profit. This would drastically reduce the price of a single Landsat scene from as much as $4,400 to about $500 (Asker, May 11, 1992). Officials of NASA and the Departments of Defense, Commerce and the Interior maintain that Pressler's proposal would be too rigid, needlessly tying the hands of future policy-makers trying to promote easy access to remote sensing data (Asker, May 11, 1992).

Bush Administration officials maintain that they can accomplish similar goals with NSPD 5.

3. National Space Policy Directive 5 (NSPD5) (<u>Land Remote Sensing Strategy</u>)

In its realignment of the future for the Landsat program, NSPD 5, which was signed by President Bush 5 February 1992, identifies three major goals for the U. S. government:

- Provide Landsat data which is consistent with previous Landsat data (Landsats-1 through -5);
- Availability of Landsat data to national security, global change research and other federal users;
- Promote private sector commercial opportunities for Landsat-type remote sensing (Bush, 1992).

NSPD 5 also lays out a Landsat strategy for the U. S., including:

- Continuity of Landsat's -4 and -5, until Landsat-6 becomes operational;
- Acquire Landsat-7 to maintain continuity of Landsat-type data beyond the projected Landsat-6 end-of-life;
- Development of advanced remote sensing technologies - reducing cost, while increasing performance;
- Minimize cost of Landsat-type data for U. S. government agencies;
- Limit U. S. government regulations affecting private sector remote sensing activities;
- Maintain an archive of Landsat images;
- Consider alternatives for maintaining continuity of data beyond Landsat-7 (Bush, 1992).

Implementing guidelines for NASA and the Departments of Commerce, Defense and Interior include the following:

- DOC - complete and launch Landsat-6; continued operations of Landsat's -4 and -5;
- DOD and NASA - develop and launch Landsat-7 satellite; with Department of Energy (DOE) and other appropriate agencies, prepare a coordinated technology plan for improving performance and reducing cost of future Landsat-type remote sensing systems;
- DOI - continue to maintain national archives (Bush, 1992).

The DOD and NASA Management Plan for the Landsat Program responded to NSPD 5. The Plan is a cooperation in the continuation of the Landsat program, including the development and operations of a Landsat follow-on (Landsat-7) satellite, as well as in planning for future operations and advanced

technology development with other appropriate agencies (Atwood and Truly, 1992).

DOD will have the lead responsibility for the acquisition and launch of the Landsat-7 satellite. NASA will have the lead responsibility for the development and operation of the Landsat ground system, including data processing, archiving, distribution, user support and mission operations management. Representatives from DOD and NASA will jointly chair the Landsat Coordinating Group (LCG), which will be responsible for top level policy and budget making decisions. NASA and DOD will each fund the portion of the program for which they are responsible. (Atwood and Truly, 1992)

Evaluating opportunities for international cooperation and utilization of Landsat will be the responsibility of NASA, with DOD support. NASA will have the lead responsibility for promoting and periodically assessing U. S. commercial opportunities. Additionally, NASA, DOD, and other U. S. government agencies are pursuing advanced technologies for future land remote sensing systems. (Atwood and Truly, 1992)

The National Space Council-member agencies reviewed the DOD/NASA Management Plan for Landsat Program and are supportive of the "streamlined management approach and assignment of responsibilities outlined in the Plan." (Albrecht, 1992)

While government control of future Landsat systems will affect EOSAT's future in remote sensing, the company said

it was pleased with the NSPD 5 directive because it "renews the federal commitment to assure data continuity and availability after Landsat-5..." (EOSAT, Spring 1992).

The Bush Administration directive specifically addresses Landsat-7, which has not yet been designed. EOSAT and others are concerned that the plans for that satellite must be drawn now to avoid a data gap. (EOSAT, Spring 1992)

EOSAT said the directive will "inspire customer confidence in the long-term availability of EOSAT's products, and thus improve the competitive stance of the U. S. land remote sensing industry". EOSAT also mentioned that the policy directive will keep the U. S. as a leader in commercial land remote sensing. EOSAT anticipates that they will have a good working relationship with DOD and NASA, and "will contribute to this policy directive...". (EOSAT, Spring 1992)

C. THE CENTRAL IMAGERY OFFICE (CIO)

The need for the new CIO being established by the Pentagon was approved by the Secretary of Defense Dick Cheney, Central Intelligence Agency (CIA) Director Robert Gates and Joint Chiefs of Staff (JCS) Chairman General Colin Powell. The CIO will coordinate production and distribution of strategic and tactical imagery, thus facilitating the sharing of information during operations. According to Vice Admiral McConnell, Director of the National Security Agency (NSA), the CIO should serve as a combat support agency to collect and distribute

photographs in much the same way that the NSA manages signals intelligence (SIGINT) ("Imagery Office Centralizes...", 1992; "Pentagon Plans...", 1992). While the Defense Mapping Agency (DMA) currently is chartered by the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD/C3I) as the MSI broker for DOD (Lesher, 1992), the CIO should take over these responsibilities. MSI responsibilities were forced upon DMA, who was never very enthusiastic about being the MSI broker for DOD (Lesher, 1992). While DMA does use MSI extensively for Mapping, Charting, and Geodesy (MC&G), its support to DOD has not been exceptional.

If DOD MSI acquisition were placed under the CIO, there would probably be more effort made to run a more efficient and timely program.

D. CURRENT NAVAL USERS OF MULTISPECTRAL IMAGERY

The Naval Space Command Detachment (NAVSPACECOM DET) in Colorado Springs, Colorado is the primary command for MSI in the Navy. To correct deficiencies that existed in providing MSI support to tactical forces during the Gulf War, NAVSPACECOM DET is organizing, staffing, and training an MSI implementation team. The primary focus of the team will be to work closely with Fleet units in identifying Fleet requirements for MSI support ("MSI Workstation...", 1992).

NAVSPACECOM DET will provide support for fleet exercises, provide technical support to naval units, develop and

implement training packages in support of the formal schools systems, conduct on-site training, and support specialized pre-deployment training needs of the Fleet and Fleet Marine Forces (FMF). NAVSPACECOM DET is funded by OP-943 for this program. Eventually, NAVSPACECOM DET will provide a one-stop shop for MSI technical issues within the Navy and Marine Corps ("MSI Workstation...", 1992).

NAVSPACECOM DET is currently supporting Naval Strike Warfare Center (NSWC) and the Navy and Marine Corps Intelligence Training Center (NMITC) ("MSI Workstation...", 1992).

Several naval intelligence centers are using MSI to support intelligence requirements. Fleet Intelligence Center Pacific (FICPAC), now JICPAC, was probably the most successful naval user of MSI during Desert Storm, and JICPAC continues its use of MSI data. Atlantic Intelligence Command (AIC) uses MSI mainly for terrain analysis (Capps, 1992). Interestingly, at both these commands, the Marines are the most avid users of MSI systems and products. At the Marine Corps Intelligence Center, (MCIC) in Quantico a handbook has been produced for Marine Corps MSI users. MCIC will be supporting Marine units with MSI (Rowan, 1992). The study conducted by the MCIC found that lack of knowledgeable consumers was the biggest problem it encountered in use of MSI (Rowan, 1992).

Lack of knowledge about MSI products and information, coupled with a lack of trained personnel to analyze the

imagery, have been the two most critical elements in increasing the use of MSI as a valuable intelligence tool. Currently, the only formal, in-depth training available is a two week class at the Defense Mapping School (DMS) (Geodynamics, 1990).

Unfortunately, in many instances Fleet or FMF consumers are unaware of MSI data, products, and capabilities available to support operations. Operators need to be made to appreciate how MSI can support their operations. Without support and use from the Fleet, valuable MSI capabilities could go away and the Landsat program would lose its biggest user.

E. COMMERCIAL VIABILITY OF LANDSAT

Studies released in 1988 concluded that a fully commercial remote sensing system will probably not be commercially viable and competitive until early in the next century without a significant amount of government support (Radzanowski, 1991). Major reasons for this are:

- Limited market for data;
- High costs involved in improving technology;
- Lack of training and consumer awareness;
- Foreign competition which may have lowered the demand for Landsat data, but which could stimulate competition (Radzanowski, 1991).

In the 1984 Remote Sensing Act, complete commercialization as originally envisaged is not possible, at least not in the short-term, but possibly over a decade or two (Radzanowski, 1991). With continued government support full commercialization may be realized (Radzanowski, 1991, 1991). Officials at EOSAT argue that commercialization is "on the verge of succeeding." (Asker, May 11, 1992) The federal subsidy to EOSAT to operate Landsats-4 and -5 ends in September of this year. If the U. S. government actually ends its support to the Landsat program then, and does not subsidize follow-on Landsats as agreed to in the 1984 Act, it could cost taxpayers millions of dollars, according to EOSAT (Asker, May 11, 1992). This is probably because the U. S. government had agreed to support the Landsat program through Landsat-7. Supporters of commercialization believe that Landsat's commercial viability cannot be judged until the government supports construction and launch of a Landsat-7 system, as originally planned (Radzanowski, 1991). All of EOSAT's foreign competitors are subsidized by their respective governments, including the French Spot Image, which does not expect to become fully commercialized until at least 1998 (Radzanowski, 1991). Others have suggested that the commercialization of Landsat was premature, and that until there is further development in commercial markets, ownership and operation of the Landsat program should be returned to the U. S. government (Radzanowski, 1991). Additionally, if the

U. S. government does not respond to the needs of the commercial market, foreign government subsidized systems may meet the needs and a resulting reliance on foreign systems may occur (Radzanowski, 1991).

VII. FOREIGN COMPETITION

> U. S. forces will one day be vulnerable to modern satellite technologies that could jeopardize their security due to the increasing availability of imaging capabilities on the world market. - Vice Admiral Studeman ("Satellite Recce...", 1992)

As suggested in some of the responses to the surveys in Chapters IV and V, our armed forces, bases and ports are vulnerable to reconnaissance by foreign satellites whose information may get into the hands of terrorists or Third World countries. As the number and sophistication of foreign land remote sensing satellites increase, these adversaries could more easily obtain MSI data that could be used in planning operations against the U. S. or its allies.

Testimony before the House Intelligence and House Science, Space and Technology Committees about the Landsat program provided details about the role of commercial imagery in Desert Shield/Storm. The session stressed concerns about Landsat data continuity and the dependence on foreign satellite systems (Gilmartin, 1991). A warning that foreign remote sensing capabilities may be limited in the next conflict or that the capability may not be there at all, was given by Major General William James, Director of the Defense Mapping Agency (DMA) (Gilmartin, 1991).

Uncertainty of access to foreign MSI during a conflict was exemplified by Spot Image during the Persian Gulf War. Spot

Image rescinded its access rules of providing data to anyone on a nondiscriminatory basis, and restricted access of imagery of the Persian Gulf region to the U. S. and French governments. Spot Image reinstated its open skies policy for the Persian Gulf region on 22 March 1991. (Radzanowski, 1991)

In his testimony before the Senate Armed Services Committee, VADM Studeman said,

> Modern technology, particularly in the area of imaging, affords now a wide-range of other countries, including people who are not friends of ours, to have access to the technical means to conduct reconnaissance in the imaging area and maybe even in some other technical areas. ("Satellite Recc...", 1992)

Two examples have been cited of how other countries are attempting to get access to satellite imaging technology. One is through foreign sales of imagery to Third World Countries. The second is that applications for licenses for the export of U. S. technology to Third World countries for related technology are continually being submitted. ("Satellite Recce...", 1992)

While some who work with remote sensing data, particularly in DOD, would prefer to see limited sales of this data and its technology to foreign countries, others would like to see more cooperation between countries. One suggestion for more cooperation is the creation of an international cooperative venture for "the developing, financing, managing, and operating [of] a commercial remote sensing satellite system."

(Radzanowski, 1991) Cooperation between two or more countries could:

- Eliminate competition for a limited market;
- Reduce development costs for new technologies;
- Eliminate the redundancy of systems worldwide;
- Significantly reduce the amount of government subsidies needed to operate such a system (Radzanowski, 1991).

Of course this type of cooperation would require international agreements on many different aspects of the system, including the negotiations on the operational framework for the system and implementation of day-to-day management processes and procedures (Radzanowski, 1991). Other agreements would have to be worked out, including:

- Distribution of high resolution data. Guidelines adopted by the United Nations (UN) General Assembly, in 1986, promote international cooperation and access to data on a nondiscriminatory basis. There is no requirement that prior consent be obtained before one country can survey another's resources. The U. S. may not want to distribute high resolution data of its own country.
- Individual countries, like the U. S., could potentially lose some degree of political and technical control over the system. This could compromise domestic services rendered to users of their particular country, if satellites have to be shared.
- Risk of potential for politicization, where one group of nations may seek to bar another nation from participating in the benefits of an international system for purely political reasons. (Radzanowski, 1991)

If the U. S. is considering international cooperation for land remote sensing, then those making decisions should be

aware that:

> ...it is the consensus of the U. S. government and industry that this option be employed only after the U. S. has developed a stable and long-term program in order to negotiate from a position of strength. If it does not, there is the potential that the U. S. will become the weaker partner with lesser participation in the venture. (Radzanowski, 1991)

Currently EOSAT and its French counterpart, Spot Image, do cooperate with each other to a certain extent. They each look at their counterpart as fellow developers of a rapidly growing market, and they are both aware of the complementary nature of their data (Asker, 13 July, 1992). Landsat sensors include broader spectral bands, which are advantageous for vegetation and bathymetric studies. Landsat also has a wider swath width than Spot, so broad area coverage is greater with Landsat. Spot data offers a finer spatial resolution, to 10-meters with its panchromatic sensors, while Landsat Thematic Mapper (TM) offers a 30-meter resolution (Asker, 13 July, 1992). Various government agencies have used Spot 10-meter resolution imagery merged with Landsat's 30-meter TM to enhance a Landsat image (Wilcox, 1992). This is beneficial because it merges information from various spectral bands of the Landsat data with the high resolution of Spot data.

Another indication of market potential for remote sensing data is seen in agreements between private companies. In early July 1992, International Business Machines (IBM) Corp.

and Spot Image Corp.[21] signed an agreement for IBM to market Spot satellite imagery (Asker, 13 July, 1992). Additionally, IBM is expected to enter the software market for geographic information systems (GIS)[22] The use of GIS or similar programs is a stronger growth area for MSI data than just selling pictures from satellites, according to Theodore Nanz, Spot Image Corp.'s president (Asker, 13 July, 1992).

Nanz has been working to "organize the remote sensing industry to make clear to researchers the capabilities that Spot and Landsat offer." (Asker, 13 July, 1992) Neither Nanz nor EOSAT's president, Arturo Silvestrini foresee strong newcomers to remote sensing in the next few years (Asker, 13 July, 1992). Silvestrini is however, concerned about India, who may be the basis of "potent commercial competition," but whose satellites do not come close to the technological state

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[21]Spot Image Corporation was established to market the French Spot Image data exclusively in the U. S. and is based in Reston, VA.

[22]GIS is a broad term covering systems that use software and hardware to manipulate and analyze a wide variety of data organized geographically. All sorts of information are combined with maps and other spatial data and accessed on work stations, or even on personal computers, to solve complex management and planning problems (Asker, 13 July, 1992). The idea of using remote sensing data, or MSI, to enhance outdated maps was used by DOD organizations during Desert Shield/Storm (Wilcox, 1992), and this application continues to be used today (Capps, 1992). Erdas Inc., of Atlanta, which was spun off by NASA and the state of Georgia, pioneered GIS, combining prototype GIS concepts developed at Harvard University to create a Landsat/GIS processing system on a micro-computer in 1978 (Asker, 13 July, 1992). Today, Erdas has sold in-house developed systems for processing remote sensing data in more than 70 countries (Asker, 13 July, 1992).

of the art systems available (Asker, 13 July, 1992). There is however, competition from foreign nations which have developed their own remote sensing capabilities and are marketing the data (Radzanowski, 1991). The following gives a brief overview of what foreign countries, or groups of countries, are doing regarding remote sensing.

A. FRANCE - SPOT IMAGE

The French launched their first commercial remote sensing satellite, Systeme Probatoire d'Observation de la Terre (SPOT-1), in February 1986 (Radzanowski, 1991). The Spot program was developed under the leadership of the French Space agency, CNES, in 1981 (Radzanowski, 1991). Major investors in the system included France, Belgium and Sweden.

Spot, like Landsat, has failed to live up to its ambitious commercial promise. The first Spot satellite was supposed to generate revenue to pay for the next satellite. So far though CNES, not Spot Image, has funded four satellites. Spot Image authorities have said that their company covers the costs of running Spot-1 and -2. (Asker, 13 July, 1992)

Spot-2 was successfully launched in January, 1990 (Radzanowski, 1991). Spot-1 was put in a hibernation mode in January 1991, but was reactivated in March of that year to meet customer needs (Lenorovitz, 1992). It will probably be placed back in hibernation in late 1992 (Lenorovitz, 1992). In 1987, the French government approved procurement of Spot-3

through public funds, but financing for Spot-4 was partially tied to the participation of the European Community (EC) (Radzanowski, 1991). Without EC participation, the approval of Spot-4 was decided by French Prime Minister Michel Rocard in July 1989. While he approved Spot-4, Rocard said that it would be the last Spot procurement on the public budget (Radzanowski, 1991). In addition to the satellites, CNES now pays more than half of Spot Image's operating costs (Radzanowski, 1991).

Spot-3 is completed and is in storage. Its launch will be determined by the operating condition of Spot-2, which is "aging normally in orbit" according to Gerard Brachet, Spot Image's chairman (Lenorovitz, 1992).

Spot-4 will probably not be launched until 1996 or 1997 depending on how Spot-3 functions. Spot-5, which is envisioned for launch in 1999 or later is planned for a 5-meter spatial resolution, and stereo imaging capability along the satellite's flight path. Spot Image is hoping that France will allocate funding in 1993 which would allow definition work for Spot-5 to start next year. Another goal for Spot-5 is to retain a fairly wide field of view for the imagery. Additionally, Spot Image wants to have Spot-5 carry one of the high-resolution visible (HRV) instruments used on the first generation satellites. This will provide data continuity for those who use this data. Obviously, France is concerned about improving its payload for Spot-5. (Lenorovitz, 1992)

As a result of lessons learned from Desert Storm, the U. S. Air Force is recommending that imagery from Spot be an integral part of reconnaissance capabilities. Spot imagery was used widely as a part of the allied air campaign against Iraq. DMA data combined with Spot imagery enabled geopositioning accuracy of less than 200 feet. According to the Spot final report from Desert Storm, "All aircrews interviewed considered coordinates and elevations derived from DMA-aligned Spot imagery to be extremely accurate and an indispensable aid for navigation and weapons delivery." (Covault, 1992) The Air Force considers procurement of additional Spot data a "fundamental element of a new operational reconnaissance imaging architecture being formed by DOD and the CIA."[23] (Covault, 1992) Additionally, the Air Force is seeking permission for "Eagle Vision"[24] which could be underway as early as 1992 (Covault, 1992). While the U. S. used Spot data extensively in support of operations during Desert Storm, the U. S. government needs to consider all aspects of dependency on foreign MSI data when contracting with another country.

Spot Image has mentioned to U. S. officials that it is "ready and willing" to take over data distribution for the

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[23]This is probably in reference to the CIO.

[24]"Eagle Vision" would be another test of Spot capabilities using a small mobile ground station to receive images in the field directly from the French satellite (Covault, 1992).

Landsat satellite, according to Brachet. Several years ago France initiated discussions with the U. S. Commerce Department on the possibility of bringing together the Spot and Landsat programs. The conversations ended and were never reinitiated. (Lenorovitz, 1992)

U. S. reliance on foreign MSI satellites and data deserves careful consideration. In the past some of our allies have not cooperated with us in granting our armed forces basing privileges or overflight permission. For example, in 1986 France refused to allow FB-111's, launching from bases in England, overflight permission to participate in the Libyan raids. In March 1987 only Portugal would allow U. S. Air Force aircraft to land and refuel enroute to Saudi Arabia; no other NATO ally would grant such permission. In this instance the Air Force F-15's and their support aircraft had to fly from the Azores non-stop to Riyahd. These are examples of the risk of reliance that U. S. government agencies must remember when considering cooperation and contracts with foreign countries.

B. THE FORMER SOVIET UNION (FSU)

The FSU has two types of land remote sensing programs. The Soyuzkarta, which is usually launched as a dedicated satellite to obtain data after the order is placed, has a spatial resolution of 5-meters (Radzanowski, 1991). The satellites can stay in orbit up to four weeks and use actual

photographic film that is exposed in orbit and ejected in a capsule that is recovered on earth (Radzanowski, 1991). On 6 May 1992, Spot Image Corp., in the U. S., signed an agreement with Central Trading Systems to share commercial distribution of Soyuzkarta images (Spotlight, 1992). These images are wide area coverage with a wide swath of 120 km (Spotlight, 1992).

The second system, the Almaz-1, launched 31 March 1991, was the first commercial radar satellite launched (Radzanowski, 1991). Originally developed for military reconnaissance, the satellite has a synthetic aperture radar (SAR) which is capable of imaging at night, through clouds and even into the water and sand to a limited degree (Radzanowski, 1991, and Asker, 13 July, 1992). Almaz images have a resolution of 15-30 meters, and the radar has a strong response from metallic objects and is sensitive to changes in soil moisture (Spotlight, 1992). Spot Image Corp. also distributes this imagery (Spotlight, 1992).

C. JAPAN

Japan has developed two remote sensing satellites since the mid-1980's when the Space Activities Commission (SAC) of Japan recommended that a series of marine and land observation satellites be developed. This recommendation resulted in the development of the Marine Observation Satellite (MOS, or MOMO) and the Japanese Earth Resources Satellite (JERS-1). (Radzanowski, 1991)

The MOS-1A satellite, launched in early 1987, is equipped with a multispectral electronic self-scanning radiometer (MESSR), a visible and thermal infrared radiometer (VTIR), and a microwave scanning radiometer (MSR) (Radzanowski, 1991, and Hatoyama-Machi, 1990). By August 1990, MOS-1A had exceeded its design life, while MOS-1B was launched earlier that year (Hatoyama-Machi, 1990). MOS-1B is expected to function until 1993 or 1994. Both these satellites are providing the Japanese with high quality MSI data (Hatoyama-Machi, 1990). Agencies and countries other then Japan receiving MOS data at their own ground stations include, ESA, Canada, France, Thailand, Australia, and the U. S. (Radzanowski, 1991).

JERS-1, launched in February 1992, is designed to carry a SAR and a visible and near infrared radiometer (VNIR) capable of stereoscopic imaging (Radzanowski, 1991). Its SAR produces high contrast and accurate determinations of topographical features in day or night, independent of vegetation cover or weather (Proctor, 1992). JERS-1 is co-sponsored by Japan's National Space Development Agency (NASDA), and the Ministry of Trade and Industry (MITI) (Hatoyama-Machi, 1990). About 300 researchers worldwide have been approved for distribution from the JERS-1 satellite (Proctor, 1992). JERS-1 data will also be exchanged with other national space agencies, including NASA (Proctor, 1992).

Japan's Advanced Earth Observing Satellite (ADEOS), originally scheduled for launch in 1995, will not be launched

until 1996 (Proctor, 1992). A combination of budget shortfalls, sensor, and integration difficulties are responsible for the ADEOS launch delay. Negotiations with international space agencies have also slowed the progress (Proctor, 1992). ADEOS will carry multiple earth and oceanographic instruments sponsored by not only Japan, but also by the U. S. and France (Hatoyama-Machi, 1990). The U. S., specifically NASA, will contribute two sensors, while France will contribute one (Hatoyama-Machi, 1990).

A key factor in Japanese space growth is in the increasing symbiotic relationship between Japan's major space contractors and the space agencies. This relationship has the potential to create a powerful Japanese global space marketing and development capability for the 21st century. Japan's space contractors have become a powerful force with political clout and they also help generate new space system users. (Tokyo, 1990)

Japan believes that the commercialization of remote sensing satellites is premature and it is unclear if Japan intends to sell MSI data on the commercial market. Japan's main purpose for utilizing remote sensing is to develop technology for potential future commercial systems and to provide the data for users who intend to use it for the benefit of the public (Radzanowski, 1991).

D. EUROPEAN SPACE AGENCY (ESA)

The ESA's Earth Remote Sensing Satellite (ERS-1) was placed into orbit, after a 75-day delay for booster repairs, on 16 July 1991 (Mecham, 22 July 1991). The ERS-1 has both scientific and commercial objectives and will monitor, among other things, the world's oceans and land usage changes (Radzanowski, 1991). The greatest use of ERS-1 is expected to be the day-night, all-weather imaging capabilities provided by its side-scanning SAR radar (Mecham, 22 July 1991). The expected life span of ERS-1 is two to three years, with the limiting factor being advanced technology components (Mecham, 13 July 1992).

An industry consortium led by Radarsat International of Canada, and including Spot Image and the Italian firm Eurimage, will all market the data from ERS-1 commercially (Radzanowski, 1991).

ERS-2 is expected to be launched in December 1994 with an instrument package similar to ERS-1 (Mecham, 13 July, 1992).

In Torrejon, Spain, the Western European Union (WEU) is planning to open a satellite data military intelligence center in October 1992 ("Center Puts WEU Closer...", 1992). The facility will be directed by a United Kingdom official for three years ("Satellite Base...", 1991). The center is part of the WEU's goal to set up a European agency to verify arms agreements by satellite, and will receive data from the U. S. Landsat, French Spot and ESA's ERS-1 satellites and analyze it

for military purposes ("Center Puts WEU Closer...", 1992). The WEU will also use this imagery data to build expertise among WEU member nations ("Satellite Base...", 1991). The WEU Assembly has urged the European Agency to establish closer relations with other European space and technology organizations as part of that goal ("Center Puts WEU Closer...", 1992).

E. CANADA

Scheduled for launch in 1994, Canada's remote sensing satellite, Radarsat, is being designed to use a SAR that can be moved and refocused to provide different angles of viewing, resolution, and size of images. This satellite is being designed for operational use instead of being experimental and the data will be sold commercially on the world market (Radzanowski, 1991).

F. INDIA

On August 29, 1991, the FSU launched the Indian remote sensing satellite (IRS-1B). The IRS-1B carries two instruments, the Linear Imaging Self Scanner (LISS) sensors-I and -II. One scanner has 72-meter spatial resolution, while the other has 32-meter resolution, and they both gather data in four spectral bands. IRS-1A was launched in 1988, and its data was collected exclusively by Indian ground stations. Data from IRS-1B may be directly available to international

ground stations for commercial purposes. India currently plans two more IRS satellites for launch in 1992 and 1996. (Radzanowski, 1991)

VIII. CONCLUSIONS

The crisis that faces U. S. MSI capabilities must be curbed. From its first use by NASA and DOI to its present day use by the U. S. military, MSI land remote sensing has gained steadily such importance that MSI information and data is now an essential tool for military operations. Landsat and Spot proved their great value in support of U. S. and allied troops during Operations Desert Shield/Storm and now many other countries have realized the importance of MSI and the data that can be gleaned from it.

To ensure that the U. S. continues to maintain the lead in MSI capabilities, not only technologically but also militarily, we must include as a minimum, the following in future planning:

1.) Increase awareness of MSI capabilities to Fleet and Fleet Marine Forces users - Lack of knowledge of MSI is the biggest obstacle to overcome in the effective use of MSI to support U. S. naval operations. To counter this extensive training and awareness must begin at the top to ensure that commanders know what is available to their intelligence officers and planners. Past and current studies by DOD, and the naval service in particular, substantiate the requirement for MSI data in support of operations. DOD, possibly through the Central Imagery Office as well as from NAVSPACECOM DET,

must ensure that awareness of MSI capabilities is expanded significantly.

2.) Timely dissemination of MSI data to the user - The second major problem with current MSI data is the lack of timeliness in support of operations. During Desert Shield/Storm EOSAT and Spot Image put forth great effort to ensure the most rapid dissemination of data to U. S. and allied forces. However, a more rapid dissemination of MSI data is required if MSI is to be incorporated into near-real time operational planning. For long term planning, such as the six months available to prepare for the Gulf War, timeliness of MSI data was not as great a factor. In contrast, U. S. forces likely will require immediate information in future operations. DOD must also develop a rapid dissemination capability to ensure MSI data is disseminated to deployed forces in near-real time.

3.) In-depth training of users - Lack of trained personnel to analyze and disseminate MSI data is another reason why MSI data has not been incorporated more rapidly in planning and intelligence. Formal training, vice on-the-job training would be preferred, but any training is better than none at all. An extensive joint training program between NAVSPACECOM DET and the Defense Mapping School, is suggested for in-depth training.

Initiative and curiosity are the reasons that FICPAC happened to have the ability to support naval forces

with MSI during Desert Storm. The Marine Gunnery Sergeant, who took it upon himself to use MSI in support of U. S. forces, did so on his own initiative. This and his curiosity about how the system worked drove him to investigate the use of MSI prior to Iraq invading Kuwait and therefore, he was ready to utilize the MSI processing system before Operation Desert Shield. The U. S. cannot rely solely on initiative such as this, we must require trained personnel to analyze MSI data in the future.

4.) Operational Security (OPSEC) - The U. S. must realize that the availability of MSI data commercially world-wide introduces a leveling of the battlefield. We need especially to guard against third world countries and their potential use of MSI in surprising U. S. forces. The possible use of MSI data by non-state actors such as terrorists and drug cartels, with money to buy data must also be guarded against.

5.) Over-reliance on foreign systems for MSI support to U. S. forces - The U. S. cannot rely on foreign MSI data, as that support may not always be available to us in future situations. While we should cooperate with our friends and allies in sharing data, as was done during Desert Shield/Storm, we should not rely solely on them. This reliability could lead to disaster in future operations if data is unavailable.

By meeting the above requirements the U. S. will continue to be the leader in MSI capabilities. Our use and analysis of

MSI must be superior to that of our potential adversaries. With the proliferation of MSI land remote sensing systems, this is the only way that the U. S. can maintain its lead in MSI capabilities.

If DOD's rapidly diminishing forces are to adequately respond to the Nation's strategic and tactical needs in a dramatically dynamic world of change, we must not overlook the potential leverage that MSI land remote sensing capabilities could offer in bringing this awesome challenge into sharper focus.

APPENDIX A - MULTISPECTRAL IMAGERY USER REQUIREMENTS SURVEY

Name:____

Current Position:______________________________

Phone Number:__________________________________

Were you previously aware of Multispectral Imagery (MSI) capabilities and implications? Yes____ No____

In what areas of planning would you like to see a more extensive use of MSI? What would you like MSI to do for you? Targeting intelligence? Indications and Warning?

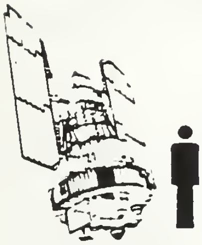
What level of distribution of MSI products or information would be desirable? Fleet Command Staff? Individual ships or squadrons?

What are your Operational Security concerns if a potential enemy can access and exploit information from the commercially available MSI products?

What would you consider to be optimum timeliness in receiving MSI products? Monthly updates? Daily updates? Contingency driven updates?

Additional comments/recommendations?

APPENDIX B - LANDSAT SPACECRAFT DATA SHEET



Landsats 1, 2, and 3

Orbit and Coverage:
Orbital Altitude: 920 km (570 mi)
Type: Circular, sun-synchronous
One orbit every 103 minutes (14 per day)
Equatorial crossing time:
- Landsat 1, 8:50 a.m.
- Landsat 2, 9:08 a.m.
- Landsat 3, 9:31 a.m.

Repeat coverage at Equator: 18 days
Inclination: 99 degrees

Sensor Packages:
Multi-Spectral Scanner (MSS)
Return-Beam Vidicon (RBV)

Spacecraft Dimensions:
Weight: 953 kg (2100 lbs)
Height: 3 m (10 ft)
Diameter: 1.5 m (5 ft)
Solar panels extend to 4 m (13 ft)

Launch Dates & Satellite Life:
Landsat 1 - July 1972 to January 1978
Landsat 2 - January 1975 to February 1982
Landsat 3 - March 1978 to March 1983

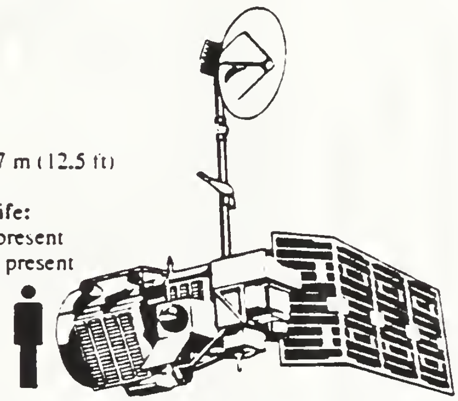
Landsats 4 and 5

Orbit and Coverage:
Orbital Altitude: 705 km (438 mi)
Type: Circular, sun-synchronous
One orbit every 98.9 minutes (14 per day)
Equatorial crossing time: 9:45 a.m.
Repeat Coverage at Equator: 16 days
Inclination: 98.2 degrees

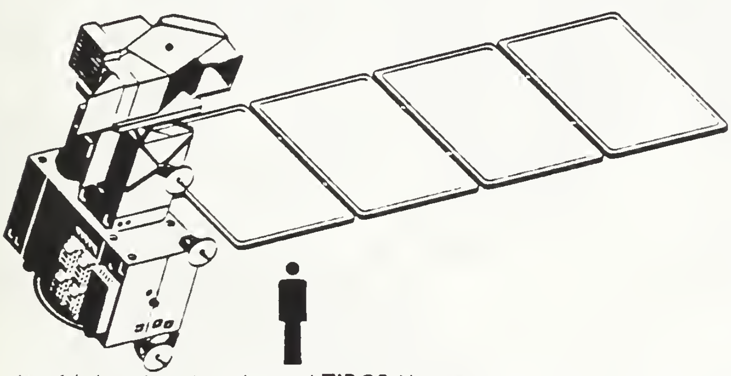
Sensor Packages:
Multi-Spectral Scanner (MSS)
Thematic Mapper (TM)

Spacecraft Dimensions:
Weight: 2200 kg (4800 lbs)
Length: 4 m (14 ft)
Width: 2 m (7 ft)
Height high-gain antenna: 3.7 m (12.5 ft)

Launch Dates & Satellite Life:
Landsat 4 - July 16, 1982 to present
Landsat 5 - March 1, 1984 to present



Based on a Multi-Mission Modular spacecraft. Landsats 4 and 5 added communications relay systems to interface with the Tracking and Data Relay Satellite System (TDRSS).



Landsat 6 is based on the Advanced TIROS-N series of polar-orbiting satellites, designed by General Electric's Astro Space Division. It will be the largest of the Landsat series, carrying the Enhanced Thematic Mapper (ETM) built by Hughes Santa Barbara Research Center, and wide-band tape recorders. The orbit characteristics are identical to those of Landsats 4 and 5. Continuity with Landsat 4 and 5 Thematic Mapper data will be assured.

Landsat 6

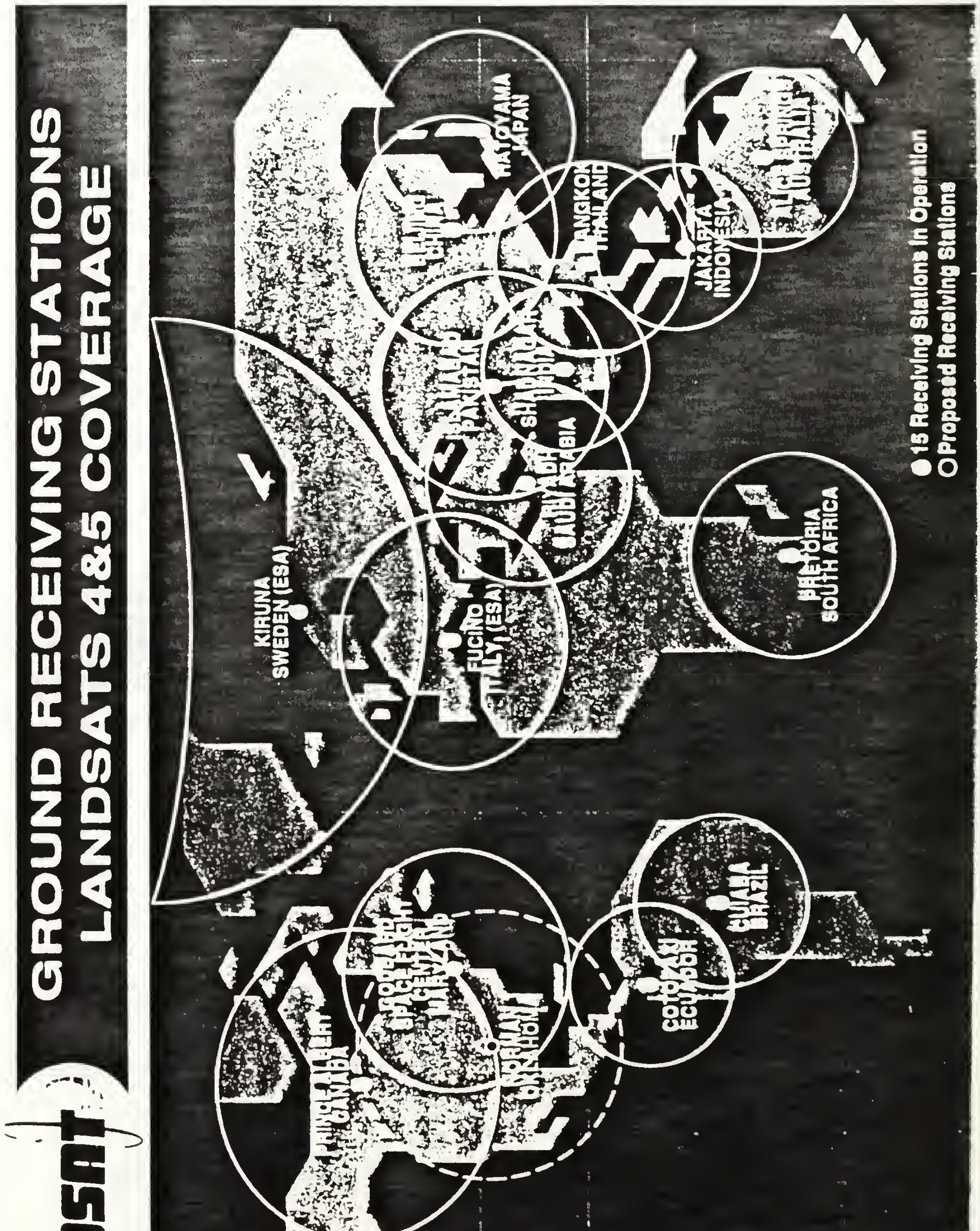
Orbit and Coverage:
Orbital Altitude: 705 km (438 mi.)
Type: Circular, sun-synchronous
One orbit every 98.9 minutes (14 per day)
Equatorial crossing time: 9:45 a.m.
Repeat coverage at Equator: 16 days
Inclination: 98.2 degrees

Sensor Package:
Enhanced Thematic Mapper (ETM)

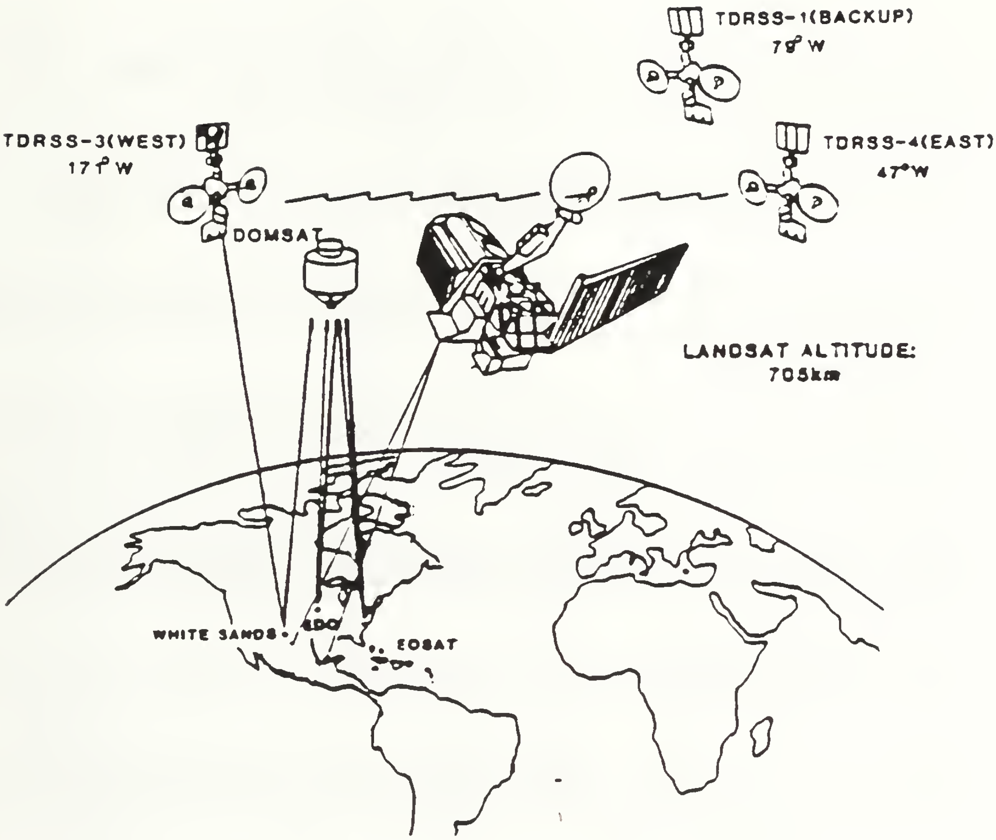
Spacecraft Dimensions:
Weight: 2700 kg (6000 lbs)
Height: 4 m (14 ft)
Width: 2 m (7 ft)
Launch Date: Mid 1992

NOTE: Spacecraft are shown at relative sizes and scaled to a six foot human figure

APPENDIX C - GROUND RECEIVING STATIONS FOR LANDSATS-4 AND -5



APPENDIX D - TRACKING AND DATA RELAY SATELLITE SYSTEM



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